Membrane-Processed Honey Samples for Pollen Characterization with Health Benefits

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Abstract

Better processing techniques must be utilized widely due to the rising demand for honey. The most common honey processing techniques are applied to melissopalynomorphs to check the quality and quantity of valuable honey using microporous ultrafiltration membranes. It is essential to have the ability to selectively filter out sugars from honey using ultrafiltration. This study authenticated 24 honey samples using membrane reactors ultrafiltration protocol to describe the pollen spectrum of dominant vegetation. The purpose of this study was also to explore nutritional benefits as well as the active phytochemical constituents of honey samples. Honey samples were collected and labeled *Acacia, Eucalyptus,* and *Ziziphus* species based on plant resources provided by local beekeepers. A variety of honeybee flora was collected around the apiaries between 2020 and 2021. Honey analysis revealed that the pollen extraction of 24 bee foraging species belonging to 14 families. The honey membrane technology verified the identities of honey and nectar sources. Also, pollen identified using honey ultrafiltration membranes revealed dominant resources: *Acacia spp.* (69%), *Eucalyptus spp.* (52%) and *Ziziphus spp.* Honey filtration using a membrane technology classified 14 samples as unifloral, represented by six dominant pollen types. The absolute pollen count in the honey sample revealed that 58.33% (n = 14) belong to Maurizio's class I. Scanning ultrasculpturing showed diverse exine patterns: reticulate, psilate, scabrate-verrucate, scabrate-gemmate, granulate, perforate, microechinate, microreticulate, and regulate to fossulate for correct identification of honey pollen types. Honey ultrafiltration should be utilized to validate the botanical sources of honey and trace their biogeographic authenticity. Thus, it is imperative to look at the alternative useful method to identify the botanical origin of filtered honey. It is critical to separate honey from adulteration by a standardized protocol. Membrane technology has yielded significant outcomes in the purification of honey.

Keywords: Honey, Membranes reactor, Honey, Pollen, Technology, Ultrafiltration

1. Introduction

Honey is mostly made up of sugars, enzymes, lipids, amino acids, organic acids, and trace amounts of minerals and ash. Honey is also high in vitamins and sugar (Barhate et al., 2003). Honey extraction and purification are becoming more popular as a result of their relevance in food, medicine, and nutraceutical. The rising demand for honey requires enhanced extraction and purification technology (Li et al., 2021).

Melissopalynology is the study of pollen collected by bees, which gives information on the flowers visited by foraging bees. Melissopalynological data could help guide floral enhancement aimed to help pollinators (Richardson et al., 2015). Honey contains a range of pollen grains, typically from plant species that honeybees feed on, and honeydew elements. Pollen analysis of honey is crucial for quality assurance and provides excellent environmental fingerprints (Von Der Ohe et al., 2004). Pollen is a useful tool in the honey analysis as it identifies the principal and minor plant species the honeybees feed. The presence of a dominant pollen concentration distinguished the unifloral honey from mixed floral honey (Selvaraju et al., 2019). Honey comprises a variety of pollen and honeydew elements that provide a visible fingerprint of the environment (Gençay et al., 2018). The botanical origin of honey is determined by the relative frequencies of the various types of pollen extracted from honey. It focuses on the identification and quantification of pollen content (Dawood et al., 2021) in honey using the membrane technique. It also detects the type and quality of honey, can be used to locate the hive and provides comprehensive data on nectar and pollen resources (Sajwani et al., 2014).

Melissopalynology has become recognized on a global scale recently. This is supported by the fact that honey is being used to treat a wide range of ailments, in addition to being valued as a nutritional supplement (Abdulrahaman et al., 2013). Pollen analysis using sensory and physicochemical tests are also required for an accurate diagnosis of botanical origin (Von Der Ohe et al., 2004). Honey demand has been increasing which needed more processing techniques to be devised. In the membrane process, the choice of membrane is extremely important. Due to the increasing demand for honey, new processing techniques need to be devised (Barhate et al., 2003). Powdered honey is still a challenge for industry and researchers. Honey is difficult to dry in its natural state because it has a high concentration of low molecular-weight carbohydrates (Samborska et al., 2019).

Honey has the potential to be used as a food supplement and it cannot be used as a nutritionally complete human dietary substitute. It has been used in medicine to treat a variety of diseases. It also boosts the immune system by monitoring the effects of anti-inflammatory, antibacterial, antifungal, and antiviral activities (Galhardo et al., 2020). Honey has a nutraceutical value, and the perception of its health and wellness-promoting qualities increases its consumption and price. The biological activity of honey was thought to be affected by the bioactive phytochemicals and the active proteins that were produced during honey production (Nichițean et al., 2021).

Thermal processing methods are commonly applied for honey purification, although they have several drawbacks (Munir et al., 2021). The main disadvantages of this procedure are a decrease in enzymatic activity (Gul et al., 2022) as well as a decrease in the number of specific minerals (Li et al., 2022). The ultrafiltration method is the most thermal approach (Qadeer et al., 2021) to obtain filtered honey among all the techniques utilized for honey sampling. Filtered honey contains a variety of minerals with significant nutraceutical potential (Karim et al., 2022). The researchers were looking for improved and better technologies (Abbas et al., 2020) (Chuah et al., 2022b) (Boulal et al., 2019) (Tawfik et al., 2021) (Bokhari et al., 2014) (Mukhtar et al., 2022) (Mukhtar et al., 2020) involving the use of membrane-based reactors (Mubashir et al., 2022) (Ali et al., 2019) due to drawbacks associated with conventional filtration methods (Bokhari et al., 2020), such as the limited mass transfer ratio and high energy input (Bet-Moushoul et al., 2016; Munir et al., 2019)

The underlying principle of membrane-based reactors is the application of selectively permeable membranes for the rapid and increased modulation of various substances such as gases, vapors, etc., (Dubé et al., 2007). The membrane reactors function in a single unit with two compartments, reducing expenses, money, and time. They are also environmentally friendly (Chuah et al., 2022a) and sustainable (Amen et al., 2021) (Dittmeyer et al., 2004). The membrane utilization honey filtration process impacts both the quality (Zahmatkesh et al., 2022) and quantity (Tan et al., 2022b) of honey, which eventually possesses antioxidant properties and high mineral content (Barhate et al., 2003)

The primary objective of this study is to use membrane-based technology (Salahuddin et al., 2022) for pollen extraction from different honey samples visited by bees. The scanning electron microscopic characterization of pollen extracted from honey is a useful tool for the accurate identification of honeybee foraging flora. Membrane-based technology also purifies honey loaded with different pollen, which has various health and nutraceutical benefits.

2. Methodology

2.1 Sampling of Honey

Honey seasonal samples were taken from four localities in the months of April, May, August, and November of 2020 (Figure 1 & 2). Each sample was collected by gently pressing out pollen and honey without harming the bees. Pollen and honey samples were collected and placed in bottles for the melissopalynological studies (Table 1). 24 honey samples were collected from various apiary sites for analysis. Fresh honey samples were collected from three replicated beehives at each apiary and placed in a polyethylene disposable jar. The samples were kept at -4 °C before analysis.

2.2 Honey Extraction via Membrane Processed Technology

Membrane-processed filtration of honey is a modern alternative to the conventional method (Pan et al., 2022) (Tan et al., 2022b) (Durrani et al., 2022). The filtration of honey samples took place using microporous flat sheet nylon and polytetrafluoroethylene (PTFE) membranes. Polytetrafluoroethylene is hydrophobic nylon membrane is water-loving and hydrophilic. The pore sizes of both membranes are 0.22 µm, and thickness is roughly 150 µm (Chaudhry et al., 2022). It was a prerequisite to sterilize the membrane with methanol for 10 hours before usage. The honey samples were filtered using a micro-membrane module. The filtered samples were collected at -4º C in a storage tank.

2.3 Honey Separation and Filtration using Membrane Reactors

The frequencies of the pollen spectrum in honey samples were calculated using the melissopalynological method recommend by the International Commission for Bee Botany (ICBB). Five-gram of each honey samples were dissolved in 10 ml of water in 30 ml falcon tubes (Louveaux et al., 1978). The diluted honey was centrifuged at 4000 rpm for 10 minutes. The supernatant liquid was decanted, and the residual sugar crystals were completely dissolved in 10 mL of distilled water. A micro-spatula was then used to reach the centrifuge tube's tip. Samples were centrifuged again for 3 to 5 minutes at 4000 rpm. The honey was then filtered using a selectively permeable microporous membrane. Purified honey was collected in a single compartment and stored in a tank. The entire sediment was spread out over three slides, covering an area of approximately 16 × 18 mm. The sediment was covered with glycerin gelatin after being dehydrated by mild heating at 30-35 °C. After that, it was liquefied by thermal treatment in a 40 °C water bath. Pollen types were identified by comparing them to the reference slides made directly from field-collected honeybee floral species and photographed with a Nikon FX-35 camera.

2.4 Honey Analysis

2.4.1 Qualitative analysis

The relative % abundances of each pollen species were calculated by an equation (Rosdi et al., 2016).

Abundance (%) =
Total number of a particular species x 100/Total number of pollen observed

The relative frequency classes of at least 300 pollen grains (PGs) were estimated following the standard nomenclature (Louveaux et al., 1978). Predominant pollen: accounts for more than 45 % pollen count, secondary pollen (16-45 %), important minor pollen (3-15 %), and minor pollen (3 %). Honey was categorized as mono-floral if pollen had a dominant representation. Otherwise, it was regarded as multi-floral.

2.4.2 Quantitative analysis

Quantitative microfiltration analysis is used (Maheshwari et al., 2022) to assess the absolute pollen counts in honey and determine whether the honey is rich or insufficient in PGs. The pollen content of each honey was measured per 10 gram (Von Der Ohe et al., 2004). 10 g of honey sample was dissolved in a beaker with 40 mL of distilled water (20-40 °C). After moistening the filtration membrane with a small amount of water, the honey solution was placed into a petri plate. The filters were placed on the sections and covered with a microscopic slide. At least 500 PGs were counted using a microscope with an appropriate magnification. The absolute number of PGs was determined by calculating the surface area of the filter's sediment-containing area (S) and the area of the microscope fields at the applied magnification (N). This procedure determined PGs present in 10 g of honey (El-Sofany et al., 2020).

$$\boldsymbol{PG/10g = S\ x\ npg\ x\ 10/s\ x\ a\ x\ p}$$

Where S is the surface area of the filter containing an area of sediment (mm^2), s is a single microscopic field size (mm^2), A is the number of fields counted, p is the weight of honey, and nPG is the total number of grains.

Honey was classified according to Maurizio's (1939) pollen classes. Class I, honey poor in pollen (PG; $<20 \times 10^3$), Class II, normal pollen (PG; $20–100 \times 10^3$), Class III, overrepresented pollen (PG; 100-500 × 10^3), Class IV, strongly overrepresented pollen (PG; 500 × 10^3-10^6), and Class V, pressed honey (PG; > 10^6).

3. Results

3.1 Membrane Quantification of Honeybee flora

The results of honey pollen analysis are presented in Tables 2, 3, and 4. Pollen analysis revealed the presence of monofloral and multifloral honey types. Only 14 monofloral honey types originating from three different foraging resources were produced when the data was pooled at the district level. Based on honey pollen count, samples from the Swabi District (ZHS), Gadoon site Nowshera (AHG), and Ziarat Kaka Sahib (AHZ) showed the richest species diversity. The 24 pollen types identified in honey samples were classified into 14 plant families (Figures 3 & 4). The 24 honey pollen types revealed 31.4% trees followed by shrubs 42.5%, and herbs 26.1%.

3.2 Qualitative Pollen Analysis

Qualitative melissopalynology identified pollen of 24 species in a variety of honey samples, with percentages ranging from 1% to 62%, and grouped into 14 families (Figures 3 & 4, Table 2). The minimum (n = 12) and maximum (n = 24) number of pollen types were observed in the *Ziziphus* honey (ZHZ) and *Eucalyptus* honey (EUK), respectively. Six types of *Acacia* and *Ziziphus* honey samples contained unknown PGs at relative frequencies of 2%, 1%, 2%, 1%, and 2%, respectively (Table 2). The quantity of two different PG types in the natural honey was examined by about 50%. *Acacia* spp. (Mimosaceae), examined in six types of honey (56%) and *Ziziphus* spp. (Rhamnaceae), detected in four types of honey (54%) (Table 2). 14 honey samples were classed as unifloral, with six major pollen types: *Acacia* spp. honey (60% AHN, 51% AHS, 55% AHG, and 62% AHGa), *Eucalyptus* spp. honey (50% both EHK and EHG) and *Ziziphus* spp. honey (51% ZHT, 50% ZHM, 49% ZHS, 51%

ZHU, 62% ZHP and 54% ZHZ).

Ten honey samples were classified as multifloral and 14 as monofloral based on the pollen types and the percentage of each species. Pollen sources are more diverse in multifloral honey than in monofloral honey. This is consistent with the findings of Bareke and Addi (2019) in the Borana Zone of Southern Ethiopia, observed a diverse spectrum of pollen types in multifloral honey. The most diverse pollen types was found in the monofloral honey sample collected at the Gulmaira site AHN (H = 3.85) Mardan district. *Acacia* species coexisted with many other honeybee foraging species that were less common in the region after the monsoon season. In the study area, *Acacia* was the most abundant (62%) honeybee foraging species. The Shannon-Weaver diversity index revealed a high diversity of honeybee foraging species in eight honey samples, with values ranging from 1.28 at the Jalala site to 3.85 at the Gulmaira site. The study area is one of the zones with the richest biodiversity explains the abundance of honeybee foragers. The diversity index values of 16 honey samples were lower, ranging from 0.05 in the Swabi site to 0.56 in the Umarzai site. This shows that the low diversity of honeybee flora is caused by the sparse distribution of bee forages. The Pielou index (F) and Shannon Weaver pollen diversity index (H) show that the resources of PGs in honey were utilized both unevenly and uniformly from the abundant pollen types (Table 2 & 3).

3.3 Quantitative Honey Analysis

The absolute count of PGs in the honey samples (n = 14) revealed 58.33% were categorized as Maurizio class I; *Acacia* honey (AHN = 18×10^3, AHS = 15×10^3, AHT = 11×10^3, AHGu = 12×10^3, AHH = 7×10^3), *Eucalyptus* honey (EHJ = 18×10^3, EHG = 18×10^3, EHU = 15×10^3, EHS = 12×10^3) and *Ziziphus* honey (ZHN = 11×10^3, ZHK = 11×10^3, ZHT = 16×10^3, ZHG = 15×10^3, ZHU = 19×10^3). Honey samples analysis ($n = 6$) revealed 25%; *Acacia* honey (AHM = 21×10^3), *Eucalyptus* honey (EHK = 22×10^3), and *Ziziphus* honey (ZHM = 23×10^3, ZHSw = 22×10^3, ZHP = 22×10^3, ZHZ = 21×10^3) were classified as Maurizio class II. While 16.66% PGs in honey samples (n = 4); *Acacia* (AHL = 235×10^3, AHG = 235×10^3, AHZ = 238×10^3) and *Ziziphus* (ZHS = 265×10^3) were catergorzied into Maurizio class III (Table 4).

4. Discussion

4.1 Nutraceutical value of Ultra filtered Honey

Membrane-based reactors were used to filter honey samples collected from diverse geographic regions. Filtered honey is again used to extract various pollen types belonging to different families and genera. Plant-based honey with the highest concentration of different pollen has nutraceutical and health benefits as mentioned in Table 5. Honey samples collected from various geographical areas indicated high mineral content.

The emphasis on nutritional potential shows the diversity of honey pollen types. Honey is utilized as an energy source as it contains carbohydrates, proteins, minerals, and antioxidants. The prepared honey products are traditional sources of food. Honeybee flora is one of the main sources of natural food-based products. Honey has a significant nutritional impact on the bioavailability of phytochemical constituents, contains antioxidants, and has a spectrum of biochemical actions related to its potency, regardless of the floral sources. The melissopalynology provides in-depth knowledge of this specialized sector to commercialize honey production and generate income for beekeepers. Pollination by honey bees is essential for human nutrition because it assures food security, creates revenue, and provides ecological services. The nutritional value of honey from several identified plant species was analyzed using membrane processing to fill in the gaps in data collection. The therapeutic properties of bee flora were explored in order to advance indigenous knowledge. The benefits of organically cooked meals and their favorable impact on health are the subjects of much research (Baig and Saeed, 2012). The utilization of honey samples has led scientists to give special attention to the health benefits. Many poor people in remote areas cannot pay the costs of modern treatments, so honeybee flora has been utilized as therapy for a number of disorders (Jamal et al., 2012). Honey is used by indigenous peoples to treat a variety of ailments, such as cough, fever, stomach pain, dysentery, renal issues, and respiratory problems. This section also discussed the various significant phytochemical active chemicals identified in honey. Phytocannabinoids, steroids, terpenoids, tannins, thiols, anthocyanins, carotenoids, coumarins, eucalyptol, and other useful substances extracted from honey (Liu et al., 2019).

4.2 Honey Analysis

In our work, photomicrographs and the correct identification of the botanical and geographical authenticity of the honey were confirmed. The data showed that pollen from trees dominated (73%). The abundance of diverse pollen spectrum suggested that the research area show rich diversity of honey foraging flora. Honey pollen content is influenced by a number of variables, including the amount of pollen produced by the melliferous species, climate, pollen diameter, pollen filtration in the honey sac, and sampling methods (Battesti and Goeury, 1992).

Honeybees collect a wide variety of PGs, but they prefer to focus on a few species (Ferreira et al., 2009). This was the first detailed melissopalynological study of several honey types produced in KPK. Furthermore, pollen extracted from the honey and analyzed provided valuable data on the flora that needs to be visited by bees. Furthermore, it has the potential to serve as a foundation for correct labeling, and authenticity criteria in the beekeeping industry.

Melissopalynology show that the PGs found in honey come from a variety of botanical sources, including farmed crops (Bokhari et al., 2017), garden plants, and wild flora. These findings were consistent with Khan et al., (2022) recently estimate pollen count from Southern Khyber Pakhtunkhwa, performed honey analysis identified 39 pollen types. The diversity of pollen found in honey samples indicated that the bee foraging flora is dominated by plants with diverse flowering periods is crucial for the honey production. Mangi et al., (2021) analyzed 16 honey samples from Sindh region explored 65 bee foraging resources classified in to 24 plant families. The melissopalynological by (Mangi et al., 2018) of natural honey analysis from Dadu district Sindh identified 25 honeybee floral species classified in to 18 families indicate the richness of bee foraging plants as a suitable source of pollen or nectar.

In a total of 24 honey samples the dominant families that are Fabaceae, Myrtaceae and Rhamnaceae, Asteraceae, Brassicaceae, and Poaceae with a considerable number of PGs indicating that honeybees frequently visited plants. Honey production depends on bee foraging species, particularly *Acacia* species. *Acacia* pollen was found in 85.5% of the analyzed samples, with *Ziziphus* honey (ZHM) from Mardan having the lowest relative frequency of just 4% and *Acacia* honey (AHGU) from Gulmaira (AHGu) having the highest relative frequency of 62%. These findings are consistent with the Cencetti et al., (2019), discovered that Fabaceae was one of the families most represented in randomly collected 12 honey samples from Burkina Faso, with PGs of the *Acacia* type identified in five samples. El-Nebir et al., (2013) previously showed that the majority of PGs were discovered in honey (43.3%) from Fabaceous species, with *Acacia nilotica* dominating the pollen spectra. Layek and Karmakar, (2018) analyzed the major nectariferous pollen types of Fabaceae (81.3%) mainly of *Acacia auriculiformis* and *Acacia nilotica*.

Morphotype diversity is a helpful melissopalynological statistic for the Myrtaceae that can be employed even in the absence of comprehensive knowledge of pollen (Sniderman et al., 2018). The palynological criteria developed for identifying *Eucalyptus* honey may not provide an adequate basis for determining the origin or validity of honey samples. Myrtaceae pollen diversity also distinguish *Eucalyptus* spp. honey from Manuka *Leptospermum* honey (Butz Huryn, 1995).

One of the unifloral honey comes from the Myrtaceae family, also includes the *Eucalyptus* species that were deliberately introduced. The two most common species are *Eucalyptus camaldulensis* and *Eucalyptus globulus*. The value of *Eucalyptus* as a source of honey is widely recognized in many countries showing different varieties (Simeão et al., 2015). According to the current data, *Eucalyptus* spp. was identified as the primary pollen in three samples. *Eucalyptus* honey importance in bee foraging compares to dominant honey types from the KPK region. *Eucalyptus* honey is recognized as some of the best honey and is extremely desirable from a consumer's point of view. The honey collected from KPK zones of monofloral *Eucalyptus* source.

Rhamnaceous pollen types, including *Ziziphus mauritiana* and *Ziziphus oxyphylla* types, were identified based on the pollen morphology of the six most important *Ziziphus* species, representing five genera from Pakistan (Perveen and Qaiser, 2005). *Ziziphus* trees are grown extensively in KPK's mountainous areas, also provide an ideal environment for the growth of floral biodiversity. Honey physiochemical parameters are influenced by the pollen inherent variability, which in turn depends on the regional floral ecology (Ali et al., 2020). *Ziziphus* spp. is the most prevalent pollen type among the 24 samples, accounting for an average of 53.2% of the five monofloral samples. According to Moraes et al., (2019), *Hovenia dulcis* (Rhamnaceae) pollen type was observed in 40% of the Santa Helena honey was present in 95% of the samples from Southern Brazil.

Honey analysis of *Ziziphus* samples foraged by *Apis mellifera* revealed that *Ziziphus* pollen accounts for 33.10% of the main pollen types in honey samples (Taha and Al-Kahtani, 2020). In another study PGs with the same botanical sources were discovered in *Ziziphus* honey (Taha et al., 2018). The pollen spectrum of Algerian honey showed that the primary melliferous species for honey production was *Ziziphus lotus* pollen, which had a mean value of 70.9% (Zerrouk et al., 2014). These findings revealed *Ziziphus* honey produced is found naturally and planted in different vegetation zones in the KPK.

4.3 Honey Pollen Ultrastructure

Scanning microscopy offered significant information that could help melissopalynological techniques (Asif et al., 2017) to identify the honey pollen spectrum (Figures 5 and 6). Pollen collected by honey bees in apiaries around the world shows that Asteraceous species pollen is mostly dominant (Telleria et al., 2019). The ultrastructure pollen traits studied used to properly identify the Asteraceous honeybee floral species frequently visited by honeybees. Azzazy, (2016) examined trizonocolporate, spheroidal, echinate with long colpus pollen in *A. squamatus*. SEM images showed the exine with echino-lophate perforate sculpture in *A. squamatus* is not in accordance with previous work. Salamah et al., (2019) defined *B. pilosa* pollen as having a spheroidal shape with an echinate surface sculpture, which contradicts our findings. Qureshi et al., (2019) analyzed the *H. annuus* pollen as prolate-spheroidal and echinate. In line with (Attique et al., 2022) classified the pollen grains of *H. annuus* as tricolpate, isopolar, echinate, and prolate-spheroidal. Monad, 3-colpate, prolate-spheroidal, conical pointed spines, and echinate exine were reported previously by Ullah et al., (2021). We observed the same pollen characters for this species regarding the type and number of apertures; however, exine stratification was defined here as echino-perforate.

Fabaceae is also a large family and is represented by a number of species in the study area. They were used as a pollen source by the honey bee foragers. Fabaceae also contributed the maximum number of species to floral diversity for the foraging of the Asiatic Honeybee (Hemalatha et al., 2018). Honeybees, visiting species of Fabaceae, may act both as pollinators and potential competitors with native pollinators, suggesting varying levels of ecological specialization (Scaccabarozzi et al., 2020). In *D. sisso*, triangular, small grains, tricolpate, triporate, isopolar, radially symmetric, and psilate tectum were recorded. Raj and Reddy (2019) also analyzed the *D. sisso* grains as euprolate, trizonoporate, and psilate was in accordance with our findings.

This study was conducted to determine the honeybee pollen preferences among the available floral diversity in Solanaceous species. In the laboratory, different pollen sources of Solanaceae were identified were collected by *A. mellifera* during the flowering season. In our study reticulate regulate pattern elements of surface exine was examined while (Amer et al., 2019) elaborate regulate-reticulate exine in *Datura stramonium.* Parveen and Qaiser in 2007 provided detailed features such as tectum striate at mesocolpium with perforations, ornamentation coarsely reticulate-rugulate show dissimilarity with our findings. Adedeji and Akinniyi, (2015) visualized that *Nicotiana tabacum* is the only species with tetracolpate pollen while in this study tricolpate grains with regulate perforate sculpture was observed. *N. tabacum* has 3-colporate pollen grains, consistent with Song et al., (2019) that the aperture of pollen grains of were mainly tricolporate.

This study also identify the Brassicaceous honeybee flora, as well as their phenology and pollen potential. The relevance of *Brassica* honey plants as nectar and pollen sources, as well as their life form, possible methods of propagation, and potential for honey production, could be emphasized (Wubie et al., 2014). In a study by Basarker (2017), the pollen of *B.*

campestris were small, tricolporate, and reticulate sculpture was similar to our findings. Another study by Yang et al., (2018) studied sub-spheroidal, trilobate, circular, tricolpate, slender, and long colpi with reticulate sculpture in *B. campestris* and found it slightly dissimilar to our observations.

Seema et al., (2019) identified bi-colporate, per-prolate, and striate types of grains in *F. vulgare*, while Puleku et al., (2018) examined granulate to rugulate exine with smooth furrows. This study also focuses on the verructae scabrate type of exine in *F. vulgare.* The pollen analyzed by (Sekina and Moore, 1995), was synocolpate, triangular with granulate sculpturing, but present results demonstrate dissimilarity with respect to psilate exine and scabrate-reticulate mesocolpium pattern. Perveen and Qaiser (2005) found sharp endpoints with tectum striate ornamentations in *Ziziphus oxyphylla* pollen morphotypes, contradicts this work revealed papillate-regulate sculpture using SEM tool. In relation to taxonomic relevance, Dinesh et al., (219) revealed the pollen biology of jujube (*Z. jujuba*) with prolate-spheroidal striate and regulate pattern exine. The current study shows that the palyno-morphs of *Z. jujuba* differ from exine sculpturing in having a reticulate stratification

Conclusion

The increasing demand for honey provides insight into more efficient methods on a large scale. Membrane technologies are particularly useful in honey commercialization. It is challenging to eliminate the microbes present in honey using conventional thermal processing methods utilized by industries. The performance of a wide range of membrane process technology in honey processing has not been evaluated. Honey ultrafiltration revealed that 14 monofloral honey samples from three bee-foraged resources were reported in various zones of the KPK. Honey samples and pollen counts show that the Swabi District site (ZHS), Gadoon District Nowshera (AHG), and Ziarat Kaka Sahib (AHZ) have high species diversity.

The pollen from 24 species was identified by the honey analysis, with percentages ranging from 1% to 62%, and grouped into 14 families. Scanning electron microscopy studies of several pollen types show diverse micromorphological sculpturing. The major honey-yielding plant species were identified using membrane-processed techniques to guide the beekeepers in better apiary management. It is recommended that future studies continue to explore honey samples to help establish a better understanding of the role of melissopalynology in the authentication of honey processed via membrane reactor technology.

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Conflict of Interest

The authors declare no potential conflict of interest regarding publication of this research work.

References

Abbas, Y., Jamil, F., Rafiq, S., Ghauri, M., Khurram, M.S., Aslam, M., Bokhari, A., Faisal, A., Rashid, U., Yun, S., Mubeen, M., 2020. Valorization of solid waste biomass by inoculation for the enhanced yield of biogas. Clean Technologies and Environmental Policy 22, 513-522.

AbdErahman, A., Abayomi, O.O., Ahmed, A.E., Nour, A.H., Yunus, R.b.M., Ibrahim, G.M., Kabbashi, N.A., 2018. Comparative analysis of polyphenolic and antioxidant constituents in dried seedlings and seedless acacia nilotica fruits. Journal of Analysis and Testing 2, 352-355.

Abdou, H.M., Hamaad, F.A., Ali, E.Y., Ghoneum, M.H., 2022. Antidiabetic efficacy of Trifolium alexandrinum extracts hesperetin and quercetin in ameliorating carbohydrate metabolism and activating IR and AMPK signaling in the pancreatic tissues of diabetic rats. Biomedicine & Pharmacotherapy 149, 112838.

Abdulrahaman, A., Solomon, O., Adeyemi, S., Liadi, M., Ahmed, R., Belewu, M., Oladele, F., 2013. Melisopalynological analysis of honey samples from jatropha plantation and Unilorin apiary farm. International Journal of Phytofuels and Allied Sciences 2, 81-92.

Abenavoli, L., Izzo, A.A., Milić, N., Cicala, C., Santini, A., Capasso, R., 2018. Milk thistle (Silybum marianum): A concise overview on its chemistry, pharmacological, and nutraceutical uses in liver diseases. Phytotherapy Research 32, 2202-2213.

Adedeji, O., Akinniyi, T., 2015. Pollen morphology of some species in the family Solanaceae. Journal of Advanced Laboratory Research in Biology 6, 125-129.

Ahmad, R., Ahmad, N., Naqvi, A.A., 2017. "Ziziphus oxyphylla": Ethnobotanical, ethnopharmacological and phytochemical review. Biomedicine & Pharmacotherapy 91, 970-998.

Ahmad, S., Zafar, M., Ahmad, M., Yaseen, G., Sultana, S., 2019. Microscopic investigation of palyno- morphological features of melliferous flora of Lakki Marwat district, Khyber Pakhtunkhwa, Pakistan. Microscopy research and technique 82, 720-730.

Akhtar, N., Ali, S.S., Ahmed, S., Samin, J., Khan, M.A., Khan, M.S., 2017. Phytochemical analysis oF lepidium didymum. Pakistan Journal of Weed Science Research 23.

Ali, H., Khan, S., Ullah, R., Khan, B., 2020. Fluorescence fingerprints of Sidr honey in comparison with uni/polyfloral honey samples. European Food Research and Technology 246, 1829-1837.

Ali, I., Rizwani, G.H., Rasheed, M., Ali, M., Hassan, A., Hassan, S., Ishrat, G., Zaheer, E., Hussain, K., Rehman, S., 2019. Chemical analysis of Dalbergia sissoo (Roxb.) pod oil by (GC-MS)/GC-FID and evaluation of antioxidant potential. Pakistan journal of pharmaceutical sciences 32.

Ali, B., Yusup, S., Quitain, A.T., Bokhari, A., Kida, T., Chuah, L.F., 2019. Heterogeneous catalytic conversion of rapeseed oil to methyl esters: Optimization and kinetic study. In Advances in Feedstock Conversion Technologies for Alternative Fuels and Bioproducts (pp 221-238) Woodhead Publishing.

Amen, R., Hameed, J., Albashar, G., Kamran, H.W., Hassan Shah, M.U., Zaman, M.K.U., Mukhtar, A., Saqib, S., Ch, S.I., Ibrahim, M., Ullah, S., Al-Sehemi, A.G., Ahmad, S.R., Klemeš, J.J., Bokhari, A., Asif, S., 2021. Modelling the higher heating value of municipal solid waste for assessment of waste-to-energy potential: A sustainable case study. Journal of Cleaner Production 287, 125575.

Amer, W.M., Hassan, R.A., Abdo, A.S., 2019. Phenoplasticity of the Egyptian Capsella bursa-pastoris (L.) Medik. morphotypes. Annals of Agriculture and Biological Research 24, 201-210.

Asif, S., Ahmad, M., Bokhari, A., Chuah, L.F., Klemeš, J.J., Akbar, M.M., Sultana, S., Yusup, S., 2017. Methyl ester synthesis of Pistacia khinjuk seed oil by ultrasonic-assisted cavitation system. Industrial Crops and Products 108, 336-347.

Attique, R., Zafar, M., Ahmad, M., Zafar, S., Ghufran, M.A., Mustafa, M.R.U., Yaseen, G., Ahmad, L., Sultana, S., Zafar, A., 2022. Pollen morphology of selected melliferous plants and its taxonomic implications using microscopy. Microscopy Research and Technique 85, 2361-2380.

Azzazy, M., 2016. Systematic importance of pollen morphology of some plants of (Lamiaceae). Current Botany 7, 5-10.

Baig, A.K., Saeed, M., 2012. Review of trends in fast food consumption. European Journal of Economics, Finance and Administrative Sciences 48, 77-85.

Barhate, R., Subramanian, R., Nandini, K., Hebbar, H.U., 2003. Processing of honey using polymeric microfiltration and ultrafiltration membranes. Journal of Food Engineering 60, 49-54.

Bartolome, A.P., Villaseñor, I.M., Yang, W.-C., 2013. Bidens pilosa L.(Asteraceae): botanical properties, traditional uses, phytochemistry, and pharmacology. Evidence-based complementary and alternative medicine Article ID 340215.

Battesti, M.-J., Goeury, C., 1992. Efficacité de l'analyse mélitopalynologique quantitative pour la certification des origines géographique et botanique des miels: le modèle des miels corses. Review of Palaeobotany and palynology 75, 77-102.

Bet-Moushoul, E., Farhadi, K., Mansourpanah, Y., Nikbakht, A.M., Molaei, R., Forough, M., 2016. Application of CaO-based/Au nanoparticles as heterogeneous nanocatalysts in biodiesel production. Fuel 164, 119-127.

Bokhari, A., Yusup, S., Asif, S., Chuah, L.F., Michelle, L.Z.Y., 2020. Process intensification for the production of canola-based methyl ester via ultrasonic batch reactor: optimization and kinetic study. In Bioreactors (pp. 27-42). Elsevier.

Bokhari, A., Yusup, S., Chuah, L.F., Klemeš, J.J., Asif, S., Ali, B., Akbar, M.M., Kamil, R.N.M., 2017. Pilot scale intensification of rubber seed (Hevea brasiliensis) oil via chemical interesterification using hydrodynamic cavitation technology. Bioresource Technology 242, 272-282.

Bokhari A., Yusup S., Faridi J.A., Kamil R.N.M., 2014, Blending study of palm oil methyl esters with rubber seed oil methyl esters to improve biodiesel blending properties, Chemical Engineering Transactions, 37, 571-576.

Boulal, A., Atabani, A.E., Mohammed, M.N., Khelafi, M., Uguz, G., Shobana, S., Bokhari, A., Kumar, G., 2019. Integrated valorization of Moringa oleifera and waste Phoenix dactylifera L. dates as potential feedstocks for biofuels production from Algerian Sahara: An experimental perspective. Biocatalysis and Agricultural Biotechnology 20, 101234

Butz Huryn, V.M., 1995. Use of native New Zealand plants by honey bees (Apis mellifera L.): a review. New Zealand journal of botany 33, 497-512.

Cencetti, T., Lippi, M.M., Nombré, I., Orioli, L., 2019. Pollen analysis of some Burkina Faso honey samples. Webbia 74, 373-381.

Chaudhry, B., Akhtar, M.S., Ahmad, M., Munir, M., Zafar, M., Alhajeri, N.S., Ala'a, H., Ahmad, Z., Hasan, M., Bokhari, A., 2022. Membrane based reactors for sustainable treatment of Coronopus didymus L. by developing Iodine doped potassium oxide membrane under Dynamic conditions. Chemosphere, 303, 135138.

Chuah, L.F., Bokhari, A., Asif, S., Klemeš, J.J., Dailin, D.J., El Enshasy, H., Yusof, A.H.M., 2022b. A Review of performance and emission characteristic of engine diesel fuelled by biodiesel. Chemical Engineering Transactions 94, 1099-1104.

Chuah, L.F., Klemeš, J.J., Bokhari, A., Asif, S., Cheng, Y.W., Chong, C.C., Show, P.L., 2022a. A review of intensification technologies for biodiesel production. Biofuels and Biorefining 87-116.

Damasceno, G.A.d.B., Ferrari, M., Giordani, R.B., 2017. Prosopis juliflora (SW) DC, an invasive specie at the Brazilian Caatinga: phytochemical, pharmacological, toxicological and technological overview. Phytochemistry reviews 16, 309-331.

Dawood, S., Koyande, A.K., Ahmad, M., Mubashir, M., Asif, S., Klemeš, J.J., Bokhari, A., Saqib, S., Lee, M., Qyyum, M.A., Show, P.L., 2021. Synthesis of biodiesel from non-edible (Brachychiton populneus) oil in the presence of nickel oxide nanocatalyst: Parametric and optimisation studies. Chemosphere 278, 130469.

Dittmeyer, R., Svajda, K., Reif, M., 2004. A review of catalytic membrane layers for gas/liquid reactions. Topics in catalysis 29, 3-27.

Dubé, M., Tremblay, A., Liu, J., 2007. Biodiesel production using a membrane reactor. Bioresource technology 98, 639-647.

Durrani, W.Z., Nasrullah, A., Khan, A.S., Fagieh, T.M., Bakhsh, E.M., Akhtar, K., Khan, S.B., Din, I.U., Khan, M.A., Bokhari, A., 2022. Adsorption efficiency of date palm based activated carbon-alginate membrane for methylene blue. Chemosphere 302, 134793.

El-Nebir, M., El-Niweiri, M., Magid, T.D.A., 2013. Identification of botanical origin and potential importance of vegetation types for honey production in the Sudan. Journal of Natural Resource Environmental Studies 1, 13-18.

El-Sofany, A., Naggar, Y.A., Naiem, E., Giesy, J.P., Seif, A., 2020. Authentication of the botanical and geographic origin of Egyptian honey using pollen analysis methods. Journal of Apicultural Research 59, 946-955.

Ferreira, E., Lencioni, C., Benassi, M., Barth, M.O., Bastos, D., 2009. Descriptive sensory analysis and acceptance of stingless bee honey. Food Science and Technology International 15, 251-258.

Galhardo, D., Garcia, R.C., Schneider, C.R., Braga, G.C., Chambó, E.D., França, D.L.B.D., Ströher, S.M., 2020. Physicochemical, bioactive properties and antioxidant of Apis mellifera L. honey from western Paraná, Southern Brazil. Food Science and Technology 41, 247-253.

Gao, L., Li, C., Wang, Z., Liu, X., You, Y., Wei, H., Guo, T., 2015. Ligustri Lucidi Fructus as a traditional Chinese medicine: A review of its phytochemistry and pharmacology. Natural product research 29, 493-510.

Gençay, Ö.Ç., Özenirler, Ç., Bayram, N.E., Zare, G., Sorkun, K., 2018. Melissopalynological analysis for geographical marking of Kars honey. Kafkas Univ Vet Fak Derg 24, 53-59.

Gul, S., Ahmad, Z., Asma, M., Ahmad, M., Rehan, K., Munir, M., Bazmi, A.A., Ali, H.M., Mazroua, Y., Salem, M.A., Akhtar, M.S., 2022. Effective adsorption of cadmium and lead using SO3H-functionalized Zr-MOFs in aqueous medium. Chemosphere 307, 135633.

Guo, S., Ge, Y., Na Jom, K., 2017. A review of phytochemistry, metabolite changes, and medicinal uses of the common sunflower seed and sprouts (Helianthus annuus L.). Chemistry Central Journal 11, 1-10.

Haider, N., Allainguillaume, J., Wilkinson, M.J., 2009. Spontaneous capture of oilseed rape (Brassica napus) chloroplasts by wild B. rapa: implications for the use of chloroplast transformation for biocontainment. Current Genetics 55, 139-150.

Hemalatha, D., Jayaraj, J., Murugan, M., Balamohan, T., Senthil, N., Chinniah, C., Suresh, K., 2018. Foraging performance of Indian honey bee Apis cerena indica (F.), during winter in Madurai district of Tamil Nadu, India. Journal of Entomology and Zoology Studies 6, 224-227.

Hossain, M.S., Koshio, S., Ishikawa, M., Yokoyama, S., Sony, N.M., Dawood, M.A., Kader, M.A., Bulbul, M., Fujieda, T., 2016. Efficacy of nucleotide related products on growth, blood chemistry, oxidative stress and growth factor gene expression of juvenile red sea bream, Pagrus major. Aquaculture 464, 8-16.

Jamal, A., Peattie, S., Peattie, K., 2012. Ethnic minority consumers' responses to sales promotions in the packaged food market. Journal of Retailing and Consumer Services 19, 98-108.

Joujeh, R., Zaid, S., Mona, S., 2019. Pollen morphology of some selected species of the genus Centaurea L.(Asteraceae) from Syria. South African Journal of Botany 125, 196-201.

Karim, S.S., Farrukh, S., Matsuura, T., Ahsan, M., Hussain, A., Shakir, S., Chuah, L.F., Hasan, M., Bokhari, A., 2022. Model analysis on effect of temperature on the solubility of recycling of Polyethylene Terephthalate (PET) plastic. Chemosphere 307, 136050.

Kaur, L., Malhi, D.S., Cooper, R., Kaur, M., Sohal, H.S., Mutreja, V., Sharma, A., 2021. Comprehensive review on ethnobotanical uses, phytochemistry, biological potential and toxicology of Parthenium Hysterophorus L.: A journey from noxious weed to a therapeutic medicinal plant. Journal of Ethnopharmacology 281, 114525.

Khan, K., Ahmad, M., Ali, M., Zafar, M., Haq, I.U., Papini, A., Yaseen, G., Sultana, S., Ahmad, S., Malik, K., 2022. Melissopalynological and biochemical profile of honeybee (Apis mellifera L.) flora in Southern Khyber Pakhtunkhwa, Pakistan. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 1-10.

Larayetan, R.A., Okoh, O.O., Sadimenko, A., Okoh, A.I., 2017. Terpene constituents of the aerial parts, phenolic content, antibacterial potential, free radical scavenging and antioxidant activity of Callistemon citrinus (Curtis) Skeels (Myrtaceae) from Eastern Cape Province of South Africa. BMC complementary and alternative medicine 17, 1-9.

Layek, U., Karmakar, P., 2018. Nesting characteristics, floral resources, and foraging activity of Trigona iridipennis Smith in Bankura district of West Bengal, India. Insectes sociaux 65, 117-132.

Li, M., Wang, Y., Shen, Z., Chi, M., Lv, C., Li, C., Bai, L., Thabet, H.K., El-Bahy, S.M., Ibrahim, M.M., Chuah, L.F., 2022. Investigation on the evolution of hydrothermal biochar. Chemosphere 307, 135774.

Li, M., Han, N., Zhang, X., Wang, S., Jiang, M., Bokhari, A., Zhang, W., Race, M., Shen, Z., Chen, R., Mubashir, M., Khoo, K.S., Teo, S.S., Show, P.L., 2021. Perovskite oxide for emerging Photo(electro)catalysis in energy and environment. Environmental Research, 112544.

Liu, J., Wang, H., Guo, M., Li, L., Chen, M., Jiang, S., Li, X., Jiang, S., 2019. Extract from Lycium ruthenicum Murr. Incorporating κ-carrageenan colorimetric film with a wide pH–sensing range for food freshness monitoring. Food Hydrocolloids 94, 1-10.

Louveaux, J., Maurizio, A., Vorwohl, G., 1978. Methods of melissopalynology. Bee world 59, 139-157.

Maheshwari, P., Haider, M.B., Yusuf, M., Klemeš, J.J., Bokhari, A., Beg, M., Al-Othman, A., Kumar, R., Jaiswal, A.K., 2022. A review on latest trends in cleaner biodiesel production: Role of feedstock, production methods, and catalysts. Journal of Cleaner Production 355, 131588.

Mangi, J., Tahir, S., Tahir, M., Rajput, M., 2018. Pollen Analysis of Natural Honey Collected from District Dadu, Sindh Pakistan. Sindh University Research Journal-SURJ (Science Series) 50, 327-334.

Mangi, J.U., Soomro, N.U.A., Jilani, N.S., Ghoto, S.A., Panhwar, M., Jamali, A.R., 2021. Pollen Analysis: Using Melissopalynology To Determine The Bee-Foraged Sources From Tando Allah Yar And Tando Muhammad Khan, Two Agriculturally Important Districts Of Sindh, Pakistan. Pakistan Journal of Botany, 53, 2157-2169.

Mubashir, M., Ashena, R., Bokhari, A., Mukhtar, A., Saqib, S., Ali, A., Saidur, R., Khoo, K.S., Ng, H.S., Karimi, F., Karaman, C., Show, P.L., 2022. Effect of process parameters over carbon-based ZIF-62 nano-rooted membrane for environmental pollutants separation. Chemosphere 291, 133006.

Mukhtar, A., Saqib, S., Lin, H., Hassan Shah, M.U., Ullah, S., Younas, M., Rezakazemi, M., Ibrahim, M., Mahmood, A., Asif, S., Bokhari, A., 2022. Current status and challenges in the heterogeneous catalysis for biodiesel production. Renewable and Sustainable Energy Reviews 157, 112012.

Mukhtar, A., Saqib, S., Mellon, N.B., Rafiq, S., Babar, M., Ullah, S., Muhammad, N., Khan, A.L., Ayoub, M., Ibrahim, M., Maqsood, K., Bustam, M.A., Al-Sehemi, A.G., Klemeš, J.J., Asif, S., Bokhari, A., 2020. A review on CO2 capture via nitrogen-doped porous polymers and catalytic conversion as a feedstock for fuels. Journal of Cleaner Production 277, 123999.

Munir, M., Ahmad, M., Mubashir, M., Asif, S., Waseem, A., Mukhtar, A., Saqib, S., Siti Halimatul Munawaroh, H., Lam, M.K., Shiong Khoo, K., Bokhari, A., Loke Show, P., 2021. A practical approach for synthesis of biodiesel via non-edible seeds oils using trimetallic based montmorillonite nano-catalyst. Bioresource Technology 328, 124859.

Munir, M., Saeed, M., Ahmad, M., Waseem, A., Sultana, S., Zafar, M., Srinivasan, G.R., 2019. Optimization of novel Lepidium perfoliatum Linn. Biodiesel using zirconium-modified montmorillonite clay catalyst. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1-16.

Nichițean, A.L., Constantinescu-Aruxandei, D., Oancea, F., 2021. Health Promoting Quality of the Romanian Honey. Scientific Bulletin, 26(1), 32-41.

Patocka, J., Bhardwaj, K., Klimova, B., Nepovimova, E., Wu, Q., Landi, M., Kuca, K., Valis, M., Wu, W., 2020. Malus domestica: A review on nutritional features, chemical composition, traditional and medicinal value. Plants 9, 1408.

Pan, L., Fang, J., Wang, F., Shang, Z., Chen, Y., Li, J., Tian, L., Yang, Y., Alruqi, M., Ahmad, Z., Malik, S., Bokhari, A., 2022. Sedimentary environment and relative sea level changes revealed by marine biological membrane. Chemosphere 305, 135378.

Perveen, A., Qaiser, M., 2005. Pollen flora of Pakistan-XLIV. Rhamnaceae. Pakistan Journal of Botany 37, 195.

Qadeer, M.U., Ayoub, M., Komiyama, M., Khan Daulatzai, M.U., Mukhtar, A., Saqib, S., Ullah, S., Qyyum, M.A., Asif, S., Bokhari, A., 2021. Review of biodiesel synthesis technologies, current trends, yield influencing factors and economical analysis of supercritical process. Journal of Cleaner Production 309, 127388.

Qureshi, M.N., Talha, N., Ahmad, M., Zafar, M., Ashfaq, S., 2019. Morpho- palynological investigations of natural resources: A case study of Surghar mountain district Mianwali Punjab, Pakistan. Microscopy research and technique 82, 1047-1056.

Raj, P.R., Reddy, A., 2019. Pollen morphology study of Leguminosae family from Manchippa Reserve Forest, Nizamabad district, Telangana. Journal of Tree Sciences 38, 70-84.

Richardson, R.T., Lin, C.H., Quijia, J.O., Riusech, N.S., Goodell, K., Johnson, R.M., 2015. Rank- based characterization of pollen assemblages collected by honey bees using a multi- locus metabarcoding approach. Applications in plant sciences 3, 1500043.

Rosdi, I.N., Selvaraju, K., Vikram, P., Thevan, K., Arifullah, M., 2016. Melissopalynological analysis of forest honey from north Malaysia. Journal of Tropical Resources and Sustainable Science (JTRSS) 4, 128-132.

Sajwani, A., Farooq, S.A., Bryant, V.M., 2014. Studies of bee foraging plants and analysis of pollen pellets from hives in Oman. Palynology 38, 207-223.

Salahuddin, Z., Ahmed, M., Farrukh, S., Ali, A., Javed, S., Hussain, A., Younas, M., Shakir, S., Bokhari, A., Ahmad, S., Hanbazazah, A.S., 2022. Challenges and issues with the performance of boron nitride rooted membrane for gas separation. Chemosphere 308, 136002.

Salamah, A., Luthfikasari, R., Dwiranti, A., 2019. Pollen morphology of eight tribes of asteraceae from universitas indonesia campus, depok, Indonesia. Biodiversitas Journal of Biological Diversity 20, 152-159.

Samborska, K., Jedlińska, A., Wiktor, A., Derewiaka, D., Wołosiak, R., Matwijczuk, A., Jamróz, W., Skwarczyńska-Maj, K., Kiełczewski, D., Błażowski, Ł., 2019. The effect of low-temperature spray drying with dehumidified air on phenolic compounds, antioxidant activity, and aroma compounds of rapeseed honey powders. Food and Bioprocess Technology 12, 919-932.

Sarwar, W., 2016. Pharmacological and phytochemical studies on Acacia modesta Wall; A review. Journal of Phytopharmacology 5, 160-166.

Scaccabarozzi, D., Guzzetti, L., Phillips, R.D., Milne, L., Tommasi, N., Cozzolino, S., Dixon, K.W., 2020. Ecological factors driving pollination success in an orchid that mimics a range of Fabaceae. Botanical Journal of the Linnean Society 194, 253-269.

Seema, N., Hamayun, M., Ullah, A., Zakaria, M., Khan, R., 2019. 21. Implication of light and scanning electron microscopy of foliar cuticular and palynological features in the correct identification of medicinal plants. Pure and Applied Biology (PAB) 8, 199-207.

Sekina, M.A., Moore, P.D., 1995. Morphological studies of the pollen grains of the semi-arid region of Egypt. Flora 190, 115-133.

Selvaraju, K., Vikram, P., Soon, J.M., Krishnan, K.T., Mohammed, A., 2019. Melissopalynological, physicochemical and antioxidant properties of honey from West Coast of Malaysia. Journal of food science and technology 56, 2508-2521.

Šiler, B., Mišić, D., 2016. Biologically active compounds from the genus Centaurium sl (Gentianaceae): current knowledge and future prospects in medicine. Studies in natural products chemistry 49, 363-397.

Simeão, C., Silveira, F., Sampaio, I., Bastos, E., 2015. Pollen analysis of honey and pollen collected by Apis mellifera Linnaeus, 1758 (Hymenoptera, Apidae), in a mixed environment of Eucalyptus plantation and native cerrado in Southeastern Brazil. Brazilian Journal of Biology 75, 821-829.

Sniderman, A.D., Couture, P., Martin, S.S., DeGraaf, J., Lawler, P.R., Cromwell, W.C., Wilkins, J.T., Thanassoulis, G., 2018. Hypertriglyceridemia and cardiovascular risk: a cautionary note about metabolic confounding. Journal of lipid research 59, 1266-1275.

Song, Y., Gu, L., Liu, J., 2019. Pollen morphology of selected species from the family Solanaceae. Palynology 43, 355-372.

Suresh, Y., Rajasekar, G., Lavanya, T., Lakshminarsimhulu, B., Reddy, K.S., Reddy, S.R., 2020. Antioxidant and antidiabetic properties of isolated fractions from methanolic extract derived from the whole plant of Cleome viscosa L. Future Journal of Pharmaceutical Sciences 6, 1-18.

Taha, E.-K.A., Al-Kahtani, S., Taha, R., 2018. Comparison of Pollen Spectra and Amount of Mineral Content in Honey Produced by Apis florea F. and Apis mellifera L. Journal of the Kansas Entomological Society 91, 51-57.

Taha, E.-K.A., Al-Kahtani, S.N., 2020. The relationship between comb age and performance of honey bee (Apis mellifera) colonies. Saudi Journal of Biological Sciences 27, 30-34.

Tekuri, S.K., Pasupuleti, S.K., Konidala, K.K., Amuru, S.R., Bassaiahgari, P., Pabbaraju, N., 2019. Phytochemical and pharmacological activities of Solanum surattense Burm. f.– A review. Journal of Applied Pharmaceutical Science 9, 126-136.

Tan, X., Shen, Z., Bokhari, A., Qyyum, M.A., Han, N., 2022a. Insights on perovskite-type proton conductive membranes for hydrogen permeation. International Journal of Hydrogen Energy.doi: 10.1016/j.ijhydene.2022.08.244.

Tan, X., Alsaiari, M., Shen, Z., Asif, S., Harraz, F.A., Šljukić, B., Santos, D.M.F., Zhang, W., Bokhari, A., Han, N., 2022b. Rational design of mixed ionic–electronic conducting membranes for oxygen transport. Chemosphere 305, 135483.

Tawfik, A., Nasr, M., Galal, A., El-Qelish, M., Yu, Z., Hassan, M.A., Salah, H.A., Hasanin, M.S., Meng, F., Bokhari, A., Qyyum, M.A., Lee, M., 2021. Fermentation-based nanoparticle systems for sustainable conversion of black-liquor into biohydrogen. Journal of Cleaner Production 309, 127349

Ullah, S.A., Zafar, M., Ahmad, M., Ghufran, M.A., Bursal, E., Kilic, O., Sultana, S., Yaseen, G., Khan, S., Majeed, S., 2021. Microscopic implication and evaluation of herbaceous melliferous plants of southern Khyber Pakhtunkhwa- Pakistan using light and scanning electron microscope. Microscopy Research and Technique 84, 1750-1764.

Von Der Ohe, W., Oddo, L.P., Piana, M.L., Morlot, M., Martin, P., 2004. Harmonized methods of melissopalynology. Apidologie 35, S18-S25.

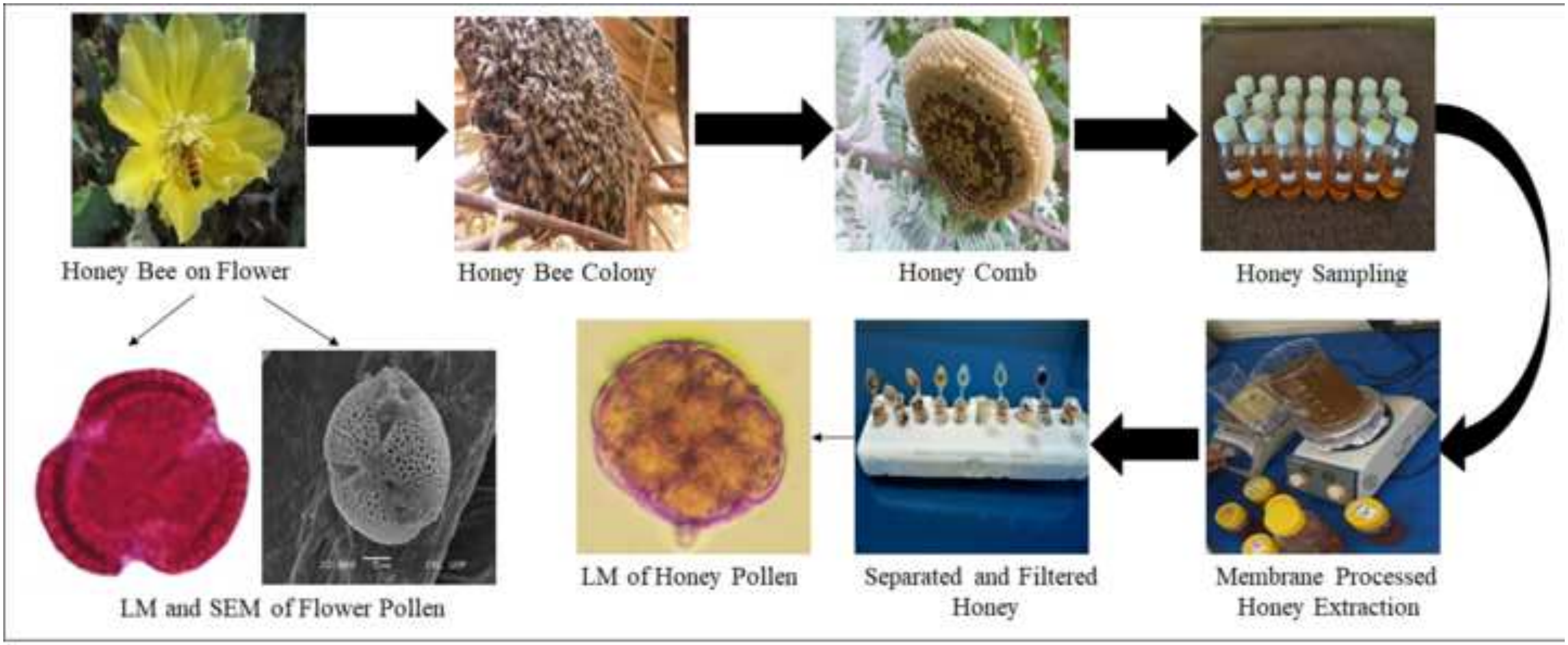
Wubie, A.J., Bezabeh, A., Kebede, K., 2014. Floral phenology and pollen potential of honey bee plants in North-East dry land areas of Amhara region, Ethiopia. IOSR Journal of Agriculture and Veterinary Science 7, 36-49.

Yang, S., Chen, S., Zhang, K., Li, L., Yin, Y., Gill, R.A., Yan, G., Meng, J., Cowling, W.A., Zhou, W., 2018. A high-density genetic map of an allohexaploid Brassica doubled haploid population reveals quantitative trait loci for pollen viability and fertility. Frontiers in plant science 9, 1161.

Zahmatkesh, S., Ni, B.-J., Klemeš, J.J., Bokhari, A., Hajiaghaei-Keshteli, M., 2022. Carbon quantum dots-Ag nanoparticle membrane for preventing emerging contaminants in oil produced water. Journal of Water Process Engineering 50, 103309.

Zerrouk, S., Seijo, M.C., Boughediri, L., Escuredo, O., Rodríguez-Flores, M.S., 2014. Palynological characterisation of Algerian honeys according to their geographical and botanical origin. Grana 53, 147-158.

Graphical Abstract



Contribution Statement

Nabila, Mushtaq Ahmad: Writing-original draft, Formal analysis, Writing- reviewing & editing

Mohamed Fawzy Ramadan, Bisha Chaudhary, Shazia Sultana: Conceptualization, Writing-original draft, Project Administration,

Muhammad Zafar: Conceptualization, Methodology, Writing- reviewing and editing.

Ashwaq T. Althobaiti, Wahid Ali: Formal writing-original draft**,** Visualization.

Khansa Masood: Writing- reviewing & editing.

Sasan Zahmatkesh, Tariq Mehmood, Mudassar Azam: Writing- reviewing & editing, Data curation.

Muhammad Saeed Akhtar, Saira Asif: Supervision, Writing- reviewing & editing.

Figure

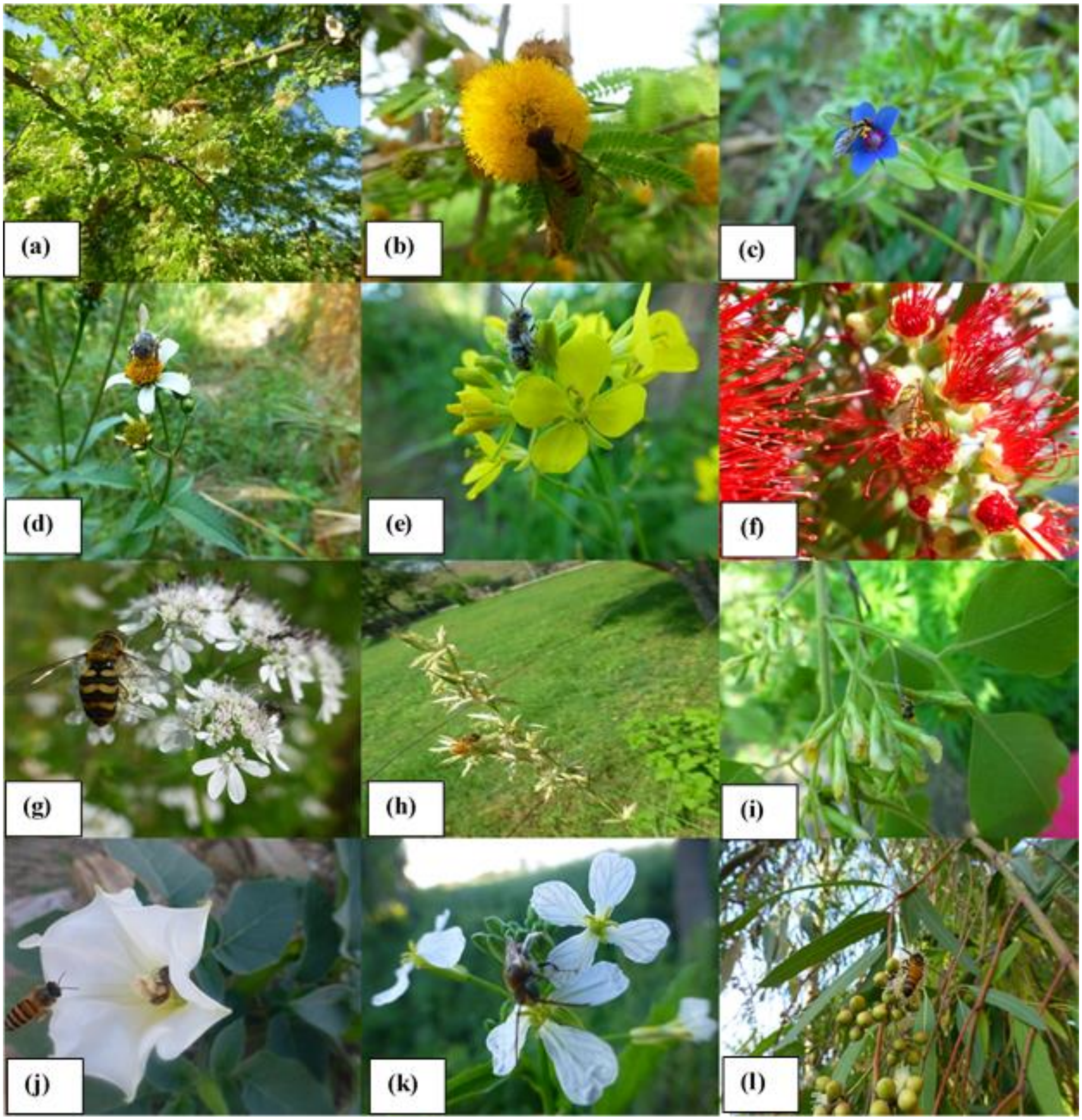


Fig 1. Honeybee foraging species: (a) *Acacia modesta* (b) *Acacia nilotica* (c) *Anagalis arvensis* (d) *Biden pilosa* (e) *Brassica campestris* (f) *Callistemon citrinus* (g) *Coriandrum sativum* (h) *Cymbopogon jwarancusa* (i) *Dalbergia sissoo* (j) *Datura stramonium* (k) *Eruca sativa* (l) *Eucalyptus camaldulensis*

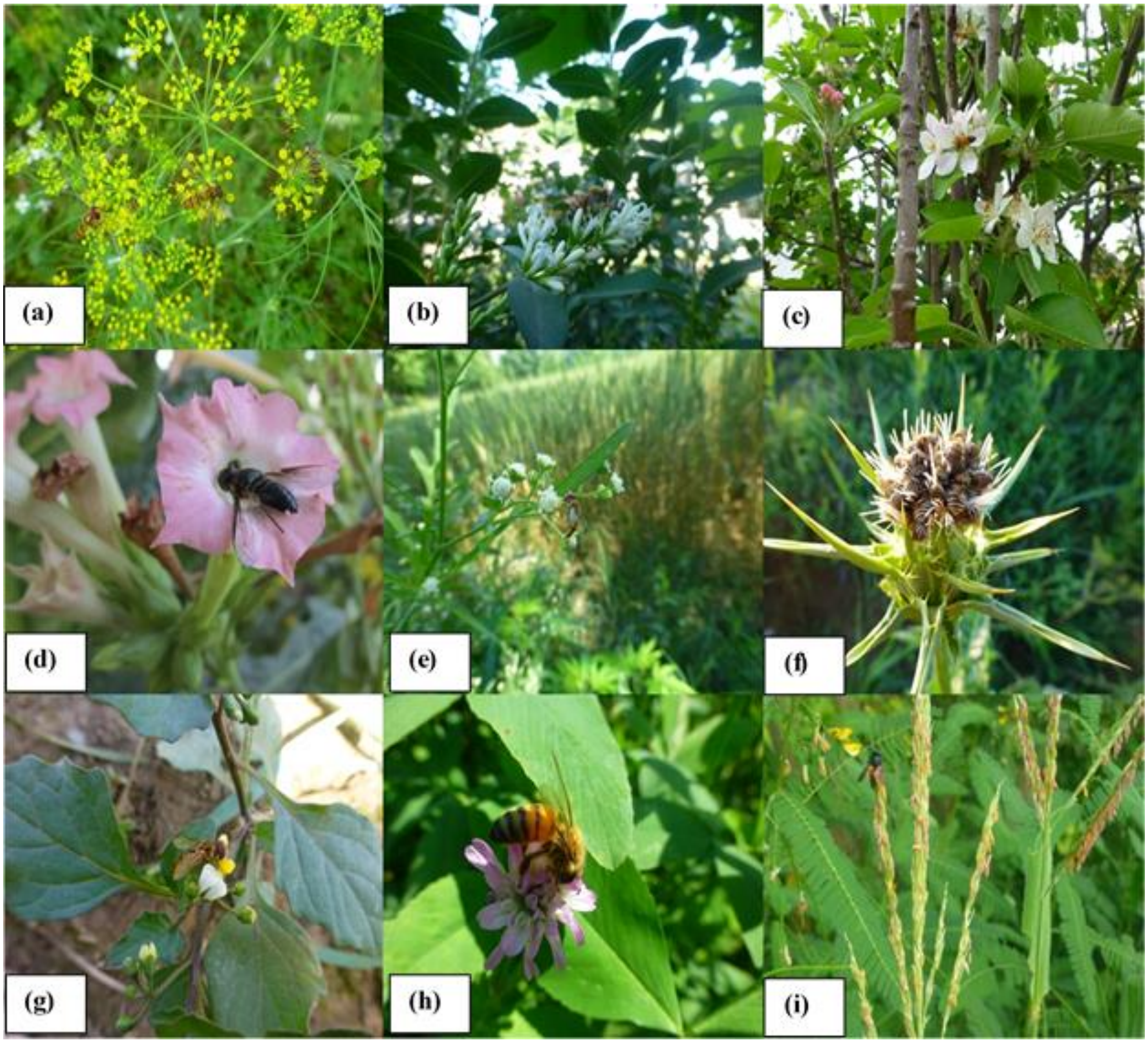


Fig 2. Honeybee foraging species: (a) *Foeniculum vulgare* (b) *Ligustium lucidium* (c) *Malus domestica* (d) *Nicotiana tabacum* (e) *Parthenium hysterophorus* (f) *Siybum marianum* (g) *Solanum nigrum* (h) *Trifolium tomentosum* (i) *Zea mays*

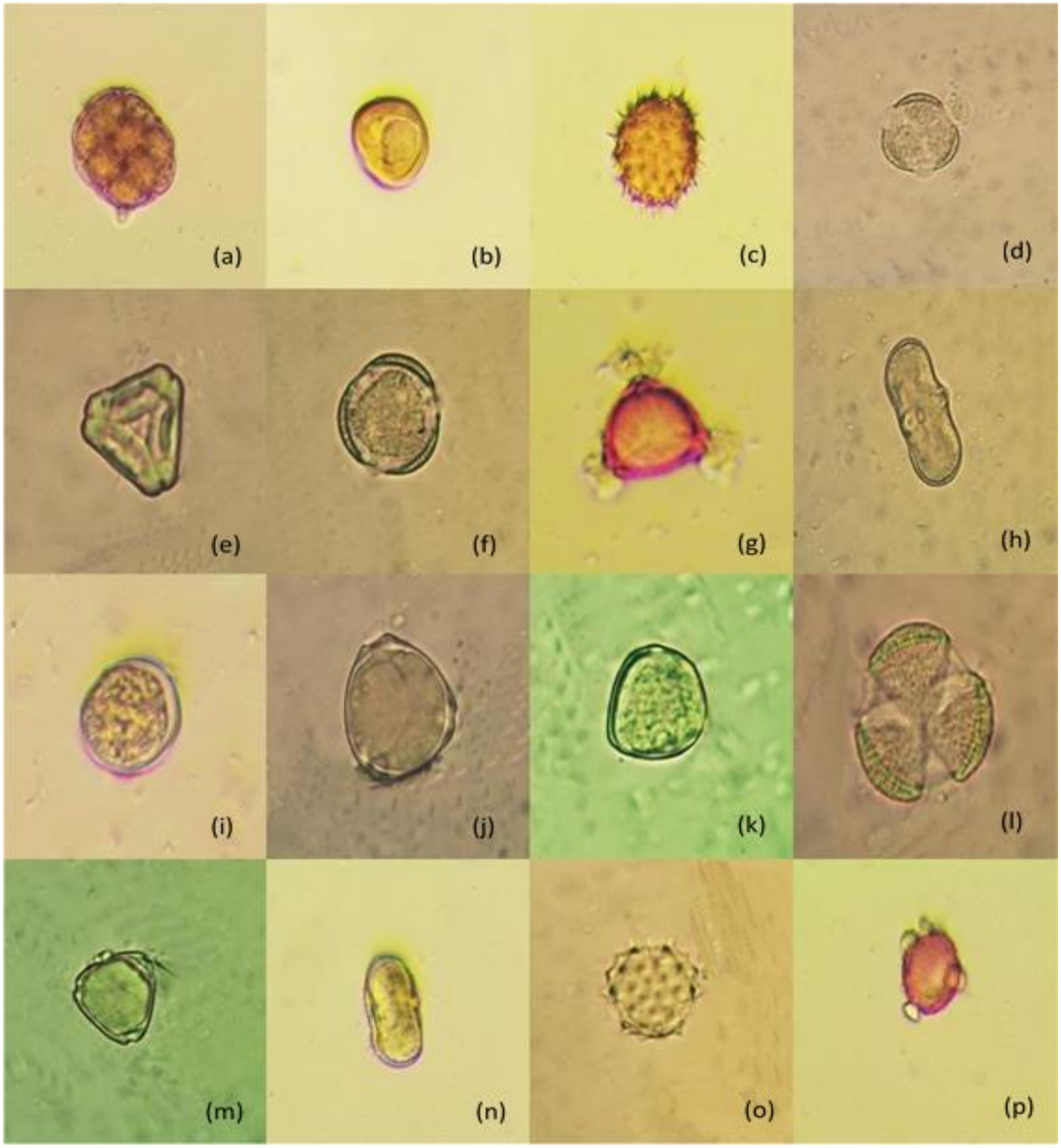


Fig 3. Photographs of diverse pollen types identified from honey samples: (a) *Acacia nilotica*, (b) *Anagalis arvensis* (c) *Biden pilosa* (d) *Brassica spp.,* (e) *Callistemon citrinus* (f) *Centaurium pulchellum* (g) *Cleome viscosa* (h) *Coriandrum sativum* (i) *Cymbopogon jwarancusa* (j) *Dalbergia sissoo* (k) *Datura spp.* (l) *Eruca sativa* (m) *Eucalyptus spp.* (n) *Foencilum vulgare* (o) *Helianthus annuus* (p) *Lantana camara*

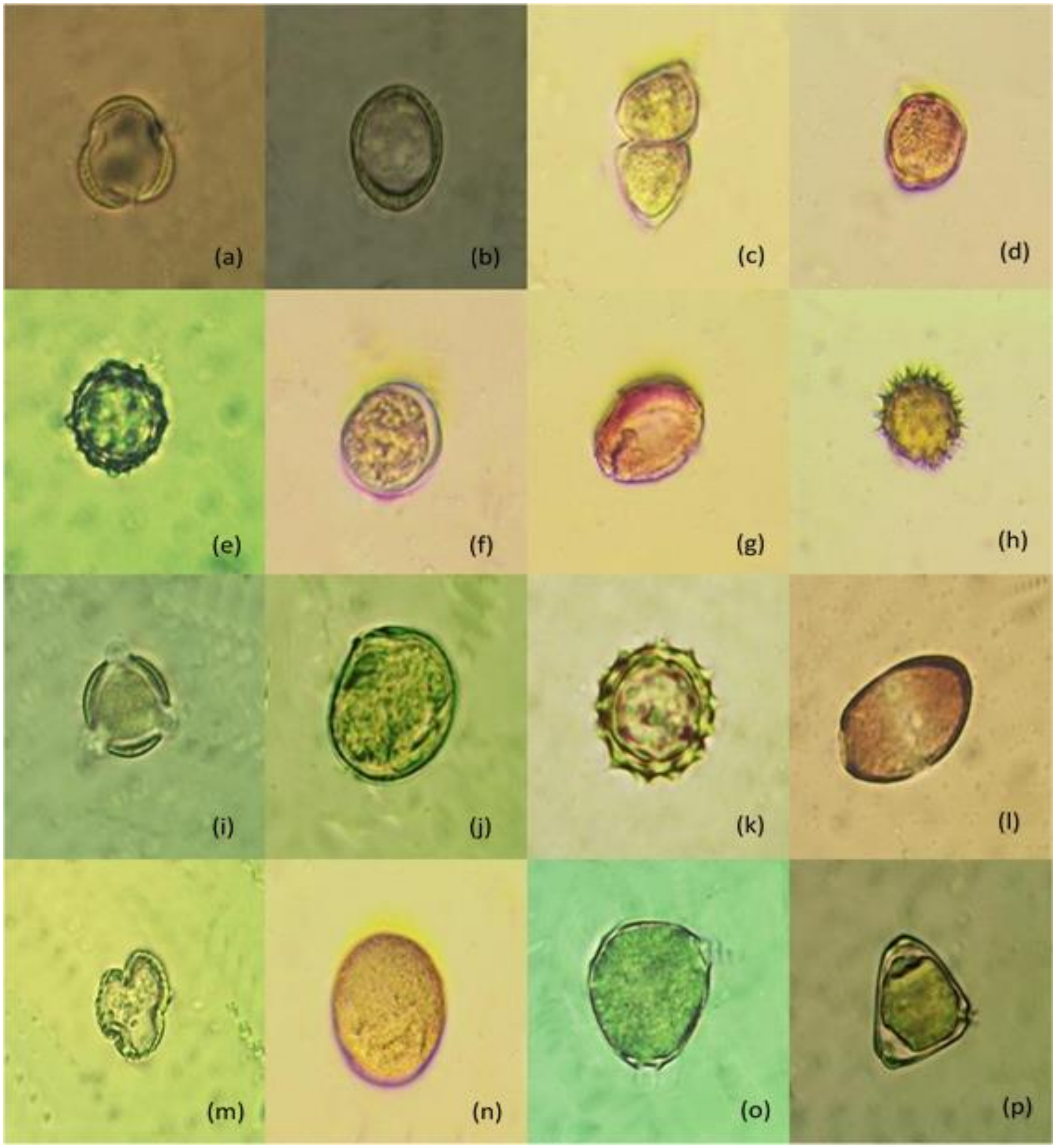


Fig 4. Photographs of diverse pollen types identified from honey samples: (a) *Lepidium spp.* (b) *Ligustium lucidium* (c) *Malus spp.* (d) *Nicotinia tabacum* (e) *Parthenium hysterophorus* (f) *Pennistum spp.* (g) *Psidium guava* (h) *Silybum marianum* (i) *Solanum spp.* (j) *Trifolium spp.* (k) *Tripleurospermum caucasicum* (l) Unknown *spp.* (m) Unknown *spp.* (n) *Zea mays* (o) *Ziziphus jujuba* (p) *Ziziphus oxyphylla*

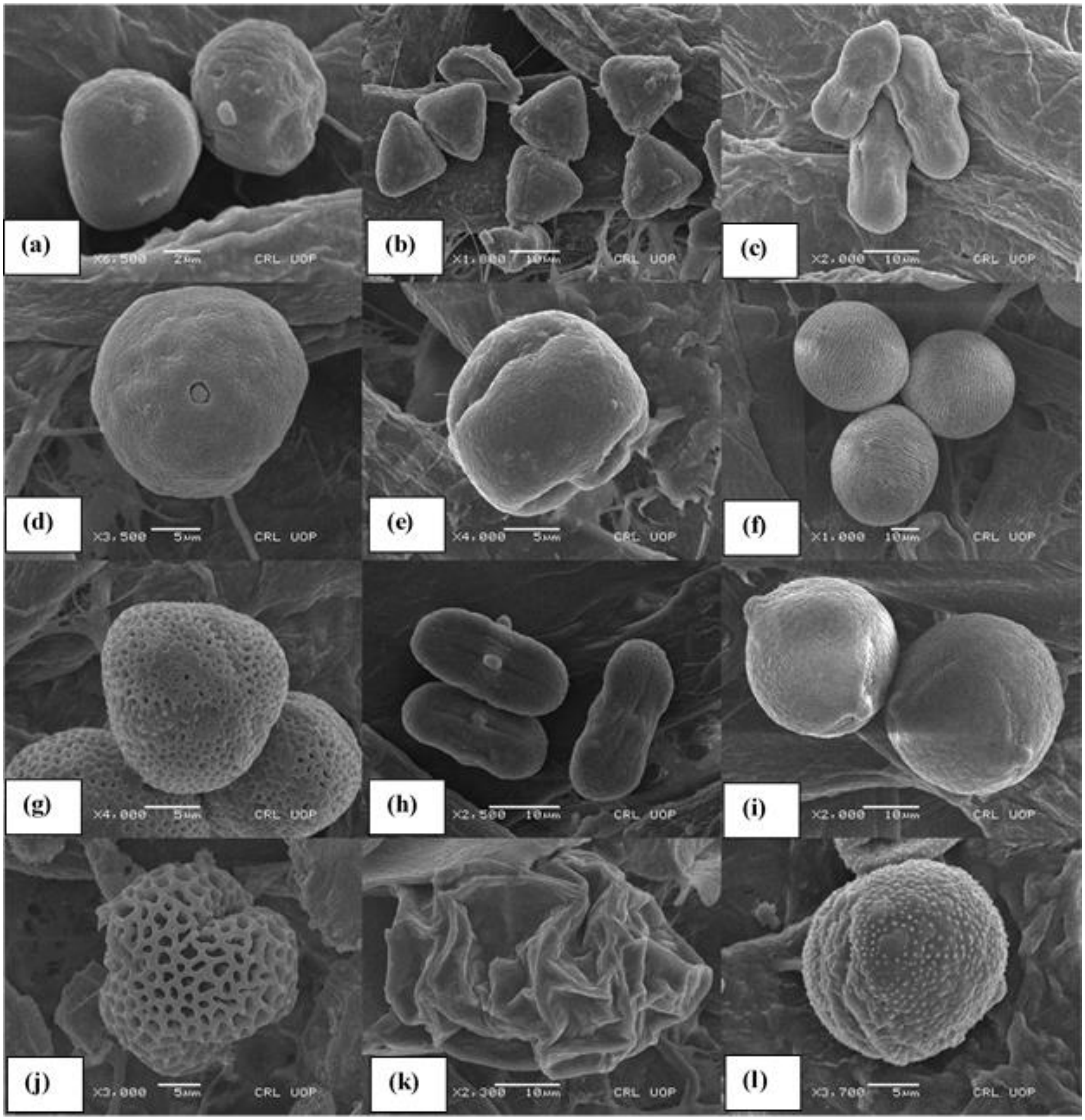


Fig 5. Scanning electron microscopic visualization of honey pollen types: (a) *Anagalis arvensis* (b) *Callistemon citrinus* (c) *Coriandrum sativum* (d) *Cymbopogon jwarancusa* (e) *Dalbergia sissoo* (f) *Datura stramonium* (g) *Eruca sativa* (h) *Foeniculum vulgare* (i) *Lantana camara* (j) *Ligustrum lucidum* (k) *Nicotiana tabacum* (l) *Papaver somniferum*

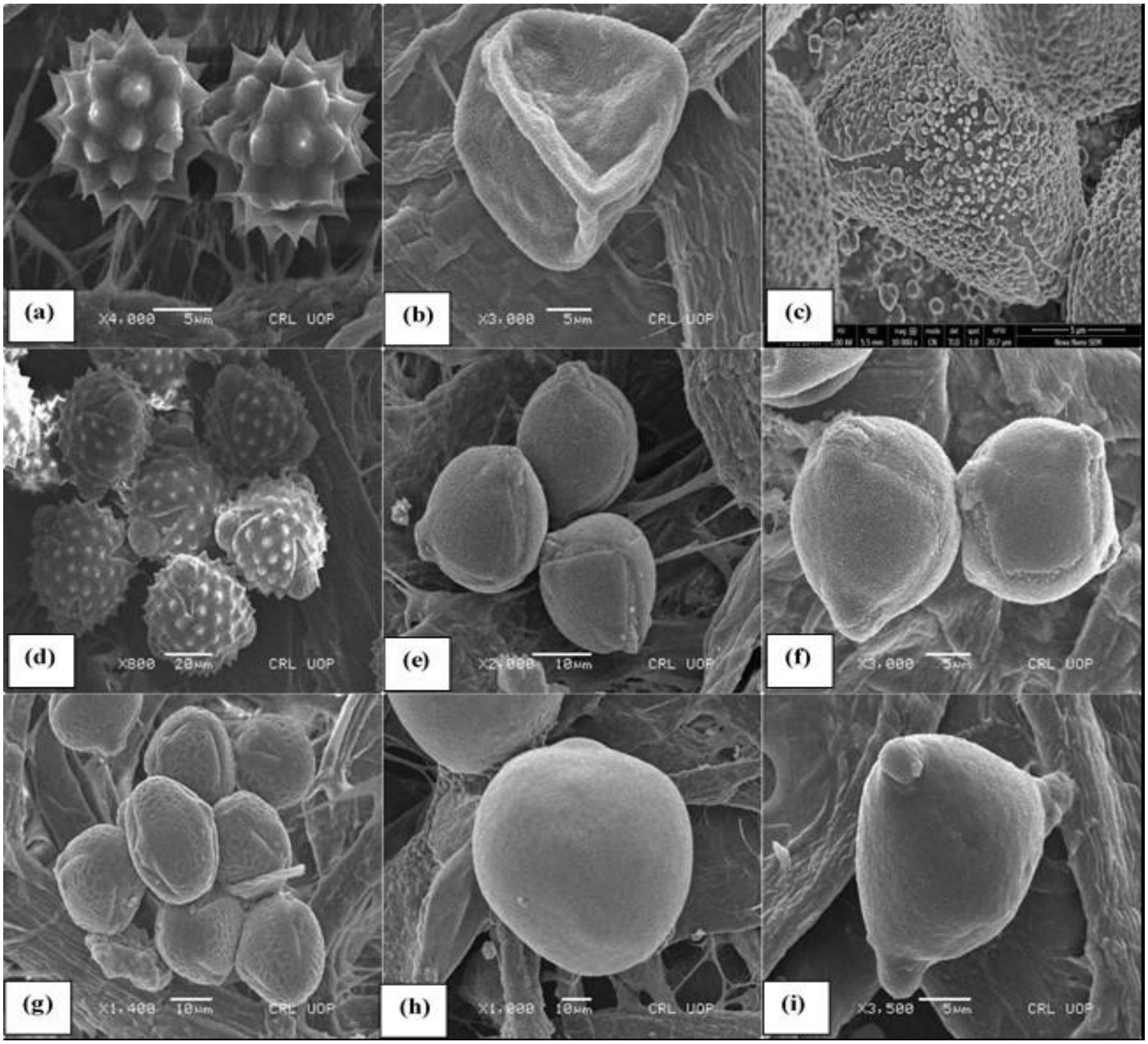


Fig 6. Scanning electron microscopic visualization of honey pollen types: (a) *Parthenium hysterophorus* (b) *Pennisetum glaucum* (c) *Psidium guava* (d) *Siybum marianum* (e) *Solanum nigrum* (f) *Solanum surattense* (g) *Trifolium tomentosum* (h) *Zea mays* (i) *Ziziphus jujuba*

Table 1. Sites of collection, periods, and honey types in apiaries, with voucher number.

S. No	Samples	Voucher No	Side of collection	Coordinates	Period	Common vegetation
1	*Acacia* Honey	AHL-13	Lundkhwar, District Mardan, KPK	34° 23,21.06"N 71°59,04.52"E	April 2020	*Acacia spp., Anagallis arvensis, Bidens spp., Callistemon citrinus, Centaurium pulchellum , Coriandrum sativum, Dalbergia spp., Datura spp., Eucalyptus spp., Eruca spp., Foeniculum vulgare, Helianthus annuus, Nicotiana tabacum, Ligustrum lucidium, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays*
2	*Eucalyptus* Honey	EHJ-5	Jalala, District Mardan, KPK.	34°20'04.33"N 71°54'27.11"E	May 2020	*Acacia spp., Bidens spp., Callistemon citrinus, Coriandrum sativum, Brassica spp., Eucalyptus spp., Tripleurospermum caucasicum, Eruca sativa, Foeniculum vulgare, Helianthus annuus, Ligustrum lucidium, Parthenium hysterophorus, Pennisetum glaucum, Silybum marianum, Ziziphus spp., Trifolium spp.*
3	*Ziziphus* Honey	ZHN-2	Nowshera District Nowshera, KPK	34°00'37.67"N 71°59'15.19"E	October 2020	*Acacia spp., Bidens spp., Centaurium pulchellum, Coriandrum sativum, Dalbergia spp., Datura spp., Eucalyptus spp., Eruca sativa, Foeniculum vulgare, Helianthus annuus, Lantana camara, Lepidium didymium, Malus domestica, Nicotiana tabacum, Parthenium hysterophorus, Ziziphus spp., Solanum spp., Silybum marianum*
4	*Acacia* Honey	AHN-7	Nowshera District Nowshera, KPK	34°00'37.67"N 71°59'15.19"E	October 2020	*Acacia spp., Anagallis arvensis, Callistemon citrinus,Cleome spp. Coriandrum sativum, Datura spp., Eucalyptus spp, Tripleurospermum caucasicum, Eruca sativa , Helianthus annuus, Lepidium didymium, Malus domestica, Ziziphus spp., Silybum marianum, Trifolium spp., Solanum spp.*
5	*Acacia* Honey	AHS-10	Shahmansoor, District Sawabi, KPK	34° 04'14.38"N 72°26'47.49"E	August 2020	*Acacia spp., Anagallis arvensis, Centaurium pulchellum, Coriandrum sativum, Brassica campestris, Dalbergia spp., Datura spp., Eucalyptus spp., Foeniculum vulgare, Psidium guava Helianthus annuus, Lepidium didymium, Nicotiana tabacum, Parthenium hysterophorus, Pennisetum glaucum, Silybum marianum, Ziziphus spp., Trifolium spp., Datura spp., Ziziphus spp.*
6	*Acacia* Honey	AHG-19	Gadoon, District Nowshera, KPK	34°10'57. 94"N 72°40'48.39"E	September 2020	*Acacia spp., Bidens spp., Cleome spp., Coriandrum sativum, Dalbergia spp., Eucalyptus spp., Tripleurospermum caucasicum, Foeniculum vulgare, Eruca spp ., Lantana camara , Psidium guava Helianthus annuus, Lepidium didymium, Ligustrum lucidium, , Nicotiana tabacum, Parthenium hysterophorus, Silybum marianum, Ziziphus spp., Trifolium spp., Datura spp., Ziziphus spp.*
7	*Acacia* Honey	AHT-21	Topi, District Sawabi,	34° 04'38.48"N	September	*Acacia spp., Anagallis arvensis, Cleome spp., Callistemon citrinus,*

			KPK	72°37'15.71"E	2020	*Brassica campestris, Centaurium pulchellum, Datura spp., Eucalyptus spp., Eruca spp., Foeniculum vulgare, Lantana camara, Malus domestica, Helianthus annuus, Nicotiana tabacum, Ligustrum lucidium, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays, Solanum spp.*
8	*Acacia* Honey	AHGu-12	Gulmaira District Mardan, KPK	71°58,31.85"N 34°23,33.61"E	May 2020	*Acacia spp., Bidens spp., Centaurium pulchellum , Coriandrum sativum, Datura spp., Eucalyptus spp., Eruca spp.,, Tripleurospermum caucasicum Helianthus annuus, Nicotiana tabacum, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays, Lepidium didymium, Parthenium hysterophorus, Solanum spp.*
9	*Eucalyptus* Honey	EHK-6	Katlang, District Mardan, KPK	34°21'07.41"N 72°04"35.20"E	May 2020	*Acacia spp., Bidens spp., Callistemon citrinus, Centaurium pulchellum , Coriandrum sativum, Dalbergia spp., Datura spp., Eucalyptus spp., Foeniculum vulgare, Helianthus annuus, Nicotiana tabacum, Ligustrum lucidium, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays,, Silybum marianum, Tripleurospermum oreades, Lantana camara, Malus domestica, Pennisetum glaucum, Solanum spp.*
10	*Ziziphus* Honey	ZHT-3	Takkar, District Mardan, KPK	34° 17'19.16"N 71°53'49.76"E	April 2020	*Acacia spp., Bidens spp., Coriandrum sativum, Dalbergia spp., Datura spp., Eucalyptus spp., Tripleurospermum caucasicum, Eruca spp., Foeniculum vulgare, Helianthus annuus, Lantana camara, Malus domestica, Lepidium didymium, Nicotiana tabacum, Ligustrum lucidium, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays, Pennisetum glaucum*
11	*Eucalyptus* Honey	EHG-9	Gulabad, District Charsadda, KPK	34°08'32.53"N 71°40'58.47"E	June 2020	*Acacia spp., Anagallis arvensis, Callistemon citrinus, Brassica campestris, Coriandrum sativum, Datura spp., Eucalyptus spp., Tripleurospermum caucasicum Eruca spp , Foeniculum vulgare, Helianthus annuus, Ligustrum lucidium,,Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays, Silybum marianum, Lepidium didymium, Parthenium hysterophorus, Pennisetum glaucum*
12	*Eucalyptus* Honey	EHU-14	Umarzai, District Charsadda, KPK	34°14'15.86"N 71°43'19.96"E	June 2020	*Acacia spp., Bidens spp., Cleome spp., Brassica campestris, Coriandrum sativum, Dalbergia spp., Eucalyptus spp., Eruca spp., Foeniculum vulgare, Helianthus annuus, Nicotiana tabacum, Parthenium hysterophorus, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays, Solanum spp.*
13	*Eucalyptus* Honey	EHS-17	Serdhari, District Charsadda, KPK	34°09'40.22"N 71°50'42.99"E	July 2020	*Acacia spp., Anagallis arvensis, Bidens spp., Callistemon citrinus, Centaurium pulchellum , Coriandrum sativum, Dalbergia spp., Datura spp., Eucalyptus spp., Tripleurospermum caucasicum , Eruca spp., Lepidium didymium, Malus domestica, Helianthus annuus, Nicotiana tabacum, Ligustrum lucidium, Psidium guava,*

						Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays, Parthenium hysterophorus, Pennisetum glaucum , Solanum spp.
14	*Acacia* Honey	AHH-19	Hathian, District Mardan, KPK	34°23'36.60"N 71°54'09.81"E	April 2020	*Acacia spp., Anagallis arvensis, Bidens spp., Callistemon citrinus, Centaurium pulchellum , Coriandrum sativum, Brassica campestris, Datura spp., Eucalyptus spp., Eruca spp., Foeniculum vulgare, Nicotiana tabacum, Pennisetum glaucum, Malus domestica, Ligustrum lucidium, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp., Zea maiz,*
15	*Ziziphus* Honey	ZHM-24	Mardan, District Mardan, KPK	34°11'42.96"N 72°02'12.41"E	May 2020	*Acacia spp., Anagallis arvensis, Callistemon citrinus, Coriandrum sativum, Brassica campestris, Datura spp., Eucalyptus spp., Eruca spp, Foeniculum vulgare, Helianthus annuus, Lepidium didymium, Malus domestica, Parthenium hysterophorus, Ligustrum lucidium, Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays*
16	*Ziziphus* Honey	ZHK-8	Karnal Sher Killi, District Sawabi, KPK	34° 14'41.48"N 72°14'40.28"E	October 2020	*Acacia spp., Bidens spp., Coriandrum sativum, Dalbergia spp., Datura spp., Eucalyptus spp., Eruca spp, Foeniculum vulgare, Helianthus annuus, Nicotiana tabacum, Lepidium didymium, Parthenium hysterophorus, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp., Zea mays*
17	*Ziziphus* Honey	ZHSw-22	Swabi, District Sawabi, KPK	34° 07'26.66"N 72°27'40.75"E	September 2020	*Acacia spp., Bidens spp., Callistemon citrinus, Coriandrum sativum, Dalbergia spp., Datura spp., Eucalyptus spp., Eruca spp., Foeniculum vulgare, Helianthus annuus, Nicotiana tabacum, Ligustrum lucidium, Psidium guava, Silybum marianum,., Ziziphus spp., Zea mays, Tripleurospermum caucasicum Lepidium didymium, Malus domestica, Pennisetum glaucum*
18	*Ziziphus* Honey	ZHS-11	Shahmansoor, District Sawabi, KPK	34° 04'14.38"N 72°26'47.49"E	November 2020	*Acacia spp., Anagallis arvensis, Bidens spp., Callistemon citrinus, Coriandrum sativum, Brassica campestris, Datura spp., Eucalyptus spp., Eruca spp., Helianthus annuus, Nicotiana tabacum, Psidium guava, Trifolium spp., Ziziphus spp., Zea mays, Silybum marianum*
19	*Ziziphus* Honey	ZHG-1	Gulabad, Dstt Charsaddai, KPK	34°08'32.53"N 71°40'58.47"E	June 2020	*Acacia spp., Bidens spp., Callistemon citrinus, Centaurium pulchellum, Brassica campestris Coriandrum sativum, Dalbergia spp., Tripleurospermum caucasicum, Eucalyptus spp., Eruca spp., Parthenium hysterophorus, Helianthus annuus, Nicotiana tabacum, Psidium guava, Trifolium spp., Ziziphus spp., Zea mays, Silybum marianum*
20	*Ziziphus* Honey	ZHU-4	Umarzai, District Charsaddai, KPK	34°14'15.86"N 71°43'19.96"E	June 2020	*Acacia spp., Anagallis arvensis, Coriandrum sativum, Brassica campestris, Datura spp., Eucalyptus spp., Tripleurospermum caucasicum, Eruca spp, Foeniculum vulgare, Helianthus annuus, Malus domestica, Pennisetum glaucum, Ligustrum lucidium,*

						Psidium guava, Trifolium spp., Ziziphus spp., Zea mays, Solanum spp.
21	*Ziziphus* Honey	ZHP-15	Pabbi, District Nowshera, KPK	34°00'27.84"N 71°47'30.85"E	June 2020	*Acacia spp., Anagallis arvensis, Callistemon citrinus Dalbergia spp., Datura spp., Eucalyptus spp., Eruca spp., Tripleurospermum caucasicum Foeniculum vulgare, Helianthus annuus, Nicotiana tabacum, Lepidium didymium, Ligustrum lucidium, Silybum marianum, Ziziphus spp.*
22	*Ziziphus* Honey	ZHZ-17	Ziarat Kaka Sahib District Nowshera, KPK	33°56'42.92"N 72°02'16.54"E	September 2020	*Acacia spp., Bidens spp., Cleome spp., Coriandrum sativum, Datura spp., Eucalyptus spp., Eruca spp., Malus domestica, Psidium guava, Silybum marianum, Trifolium spp., Ziziphus spp.*
23	*Acacia* Honey	AHZ-20	Ziarat Kaka Sahib District Nowshera, KPK	33°56'42.92"N 72°02'16.54"E	September 2020	*Acacia spp., Bidens spp., Callistemon citrinus, Coriandrum sativum, Brassica campestris, Dalbergia spp., Eucalyptus spp., Eruca spp., Helianthus annuus, Lepidium didymum, Parthenium hysterophorus Ligustrum lucidium,, Silybum marianum, Ziziphus spp., Zea mays, Solanum spp.*
24	*Acacia* Honey	AHM-18	Muqam, District Mardan, KPK	34° 12'18.75"N 72°02'05.49"E	May 2020	*Acacia spp., Bidens spp., Callistemon citrinus, Coriandrum sativum, Brassica campestris, Dalbergia spp., Eucalyptus spp., Eruca spp., Helianthus annuus, Lepidium didymum, Parthenium hysterophorus Ligustrum lucidium,, Silybum marianum, Ziziphus spp., Zea mays, Solanum spp.*

Table 2. Qualitative Melissopalynological analysis of honey collected from different botanical, seasonal, and geographical origins in KPK.

Plant species	Family	EHS-16 (%)	AHH-19 (%)	ZHM-24 (%)	ZHK-8 (%)	ZHSw-22 (%)	ZHS-11 (%)	ZHG-1 (%)	ZHU-4 (%)	ZHP-15 (%)	ZHZ-17 (%)	AHZ-20 (%)	AHM-18 (%)
Acacia spp.	Fabaceae	11	13	4	24	18	4	21	8	12	21	51	54
Anagallis arvensis	Primulaceae	1	2	1	_	_	1	_	1	2	_	_	1
Bidens spp.	Asteraceae	_	1		1	2	1	1	_	_	2	1	3
Callistemon citrinus	Myrtaceae	9	11	2	_	2	9	7	_-	1		1	2
Centaurium pulchellum	Gentianaceae	2	1	_	_	_	_	1	_	_	_	_	1
Cleome spp.	Cleomaceae		_	_	_	_	_	_	_	1	1	2	_
Coriandrum sativum	Apiaceae	2	1	2	1	2	2	_	4	_	1	_	2
Brassica campestris	Brassicaceae	_	1	1	6	_	2	1	3	_	_	1	_
Dalbergia spp.	Fabaceae	1	_	_	1	1	_	5	_	2	_	2	1

Datura spp.	Solanaceae	1	1	1	1	1	1	_	2	_	2	_	2
Eucalyptus spp.	Myrtaceae	13	5	8	5	4	15	5	8	3	6	6	2
Tripleurospermum caucasicum	Asteraceae	2	_	_	_	1	_	2	1	2	_	_	_
Eruca sativa	Brassicaceae	2	1	12	10	1	2	6	1	1	1	1	2
Foeniculum vulgare	Apiaceae	_	14	3	2	1	-	-	8	2	-	_	1
Helianthus annuus	Asteraceae	_	_	1	3	10	4	16	3	1	-	4	7
Lantana camara	Verbenaceae	-	-	_	_	_	_	-	1	_	_	_	_
Lepidium didymum	Brassicaceae	1	_	1	2	1	_	-	_	2	_	1	_
Malus domestica	Rosaceae	7	3	3	_	1	_	-	1	_	1	_	_
Nicotiana tabacum	Asteraceae	_	2	_	1	2	1	5	_	_	6	_	2
Ligustrum lucidium	Oleaceae	1	2	3	_	1		_	1	2	_	1	1
Parthenium hysterophorus	Asteraceae	2	_	1	1	_	_	2	_	_	_	1	_
Pennisetum glaucum	Poaceae	1	1	_	_	1	-	_	1	_	_	_	_
Psidium guava	Myrtaceae	_	2	_	1	_	2	1	1	_	1	_	1
Silybum marianum	Asteraceae	7	4	2	2	6	2	_	_	6	2	1	6
Solanum spp.	Solanaceae	1	_	_	_	-	1	_	4	_	_	3	_
Trifolium spp.	Fabaceae	4	13	4	2	_	2	2	2	_	2		2
Zea mays	Poaceae	3	3	1	1	4	1	2	1	_	_	1	_
Ziziphus spp.	Rhamnaceae	29	22	50	32	40	49	23	51	62	54	22	8
Unknown	Unknown	_	_	_	2	_	_	_	_	_	_	1	2
Total number of pollen grain found		333	213	654	345	643	765	432	564	645	631	686	630
Total number of pollen types		20	19	18	19	19	17	16	19	14	12	17	19
Number of unknown		-	-	-	-	-	-	-	-	-	-	1	1

pollen types												
Unknown pollen frequency (%)		_	_	2	_	_	_	_	_	_	1	2
No. of plant families in each sample	11	12	11	9	11	9	7	13	8	9	10	9
H	0.42	0.26	0.33	0.29	0.05	0.33	0.35	0.5	0.1	0.3	3.29	2.93
F	0.14	0.08	0.11	0.09	0.01	0.11	0.12	0.1	0.0	0.1	1.16	0.99

Keywords: EHS = *Eucalyptus* Honey Serdhari, AHH = *Acacia* Honey Hathian, ZHM = *Ziziphus* Honey Mardan, ZHK = *Ziziphus* Honey Karnal Sher Kili, ZHSw = *Ziziphus* Honey Swabi, ZHS = *Ziziphus* Honey Shahmansoor, ZHG = *Ziziphus* Honey Gulabad, ZHU = *Ziziphus* Honey Umarzai, ZHP = *Ziziphus* Honey Pabbi, ZHZ = *Ziziphus* Honey Ziarat Kaka Shahib, AHZ = *Acacia* Honey Ziarat Kaka Shahib, AHM = *Acacia* Honey Muqam , H = Shannon–Weaver diversity index, F = Evenneess

Table 3. Qualitative Melissopalynological analyses of honey collected from different botanical, seasonal, and geographical origins in KPK.

Plant species	**Family**	**AHL-13 (%)**	**EHJ-5 (%)**	**ZHN-2 (%)**	**AHN-7 (%)**	**AHS-10 (%)**	**AHG-19 (%)**	**AHT-21 (%)**	**AHGu-12 (%)**	**EHK-6 (%)**	**ZHT-3 (%)**	**EHG-9 (%)**	**EHU-14 (%)**
Acacia spp.	Fabaceae	24	35	41	60	51	55	33	62	7	12	17	23
Anagallis arvensis	Primulaceae	1	_	_	2	1	_	1	_	_	_	1	_
Bidens spp.	Asteraceae	3	1	3	_	_	1	_	1	1	1	_	1
Callistemon citrinus	Myrtaceae	2	6	_	2	-_	_-	5	-_	6	_	1	_
Centaurium pulchellum	Gentianaceae	1	_	1	_	2	_	1	1	1	_	_	_
Cleome spp.	Cleomaceae	_	_	-	1	_	1	1	_	_	_	_	1
Coriandrum sativum	Apiaceae	2	2	3	5	2	5	_	2	1	1	1	1
Brassica campestris	Brassicaceae	_	2	_	_	1	_	2	1	1	_	6	12
Dalbergia spp.	Fabaceae	1	_	1	_	1	4	_	_	1	1	_	1
Datura spp.	Solanaceae	2	_	3	1	2	_	3	1	1	1	1	_
Eucalyptus spp.	Myrtaceae	2	7	3	3	8	3	7	2	50	51	50	20
Tripleurospermum caucasicum	Asteraceae	_	1	_	2	_	1	_	2	1	1	1	-
Eruca sativa	Brassicaceae	2	6	1	4	_	1	2	3	_	2	2	7
Foeniculum vulgare	Apiaceae	2	2	6	_	1	2	1	_	1	1	1	3
Helianthus annuus	Asteraceae	6	5	1	4	7	3	2	1	3	2	2	2
Lantana camara	Verbenaceae	_	_	1	_	_	1	_	_	1	1	_	_
Lepidium didymum	Brassicaceae	_	_	1	2	1	2	1	2	2	2	1	_
Malus domestica	Rosaceae	_	_	3	1	_	_	1	_	3	6	_	_
Nicotiana tabacum	Asteraceae	2	_	2	_	1	1	1	2	3	1	_	1
Ligustrum lucidium	Oleaceae	1	1	_	1	1	1	5	_	2	3	1	_
Parthenium hysterophorus	Asteraceae	_	1	1	_	2	1	_	2	_	_	1	1
Pennisetum glaucum	Poaceae	_	1	_	1	1	_	1	_	1	1	1	_
Psidium guava	Myrtaceae	1	_	_	1	1	_	1	1	1	1	_	1
Silybum marianum	Asteraceae	4	13	1	2	_	5	11	2	2	1	1	2
Solanum spp.	Solanaceae	_	_	2	2	5	1	2	1	1	_	1	1
Trifolium spp.	Fabaceae	2	2	_	1	1	1	1	6	2	1	7	1

Zea mays	Poaceae	_	2	_	_	1	1	3	5	2	3	_	6
Ziziphus spp.	Rhamnaceae	10	13	6	5	10	13	23	4	6	8	6%	20
Unknown	Unknown	2	_	_	_	_	_	2	_	_	1	_	_
Total number of pollen grain found		677	543	321	546	432	734	330	332	632	448	234	453
Total number of pollen types		19	18	18	19	20	20	23	19	24	22	19	18
Number of unknown pollen types		1	-	-	-	-	-	1	-	-	1	-	-
Unknown pollen frequency (%)		2	_	_	_	_	_	2	_	_	1	_	_
No. of plant families		14	9	11	12	12	13	13	9	13	10	11	10
H		0.29	1.28	1.86	3.61	2.38	2.78	0.51	3.85	0.35	0.33	0.1	0.3
F		0.09	0.44	0.64	2.84	1.83	2.13	0.37	1.3	0.25	0.1	0.03	0.1

Keywords: AHL = *Acacia* Honey Lundkhawar, EHJ = *Eucalyptus* Honey Jalala, ZHN= *Ziziphus* Honey Nowshera, AHN = *Acacia* Honey Nowshera,, AHS = *Acacia* Honey Shahmansoor, AHG = *Acacia* Honey Gadoon, AHT = *Acacia* Honey Topi, AHGu = *Acacia* Honey Gulmaira, EHK = *Eucalyptus* Honey Katlang, ZHT = *Ziziphus* Honey Takkar, EHG = *Eucalyptus* Honey Gulabad, EHU = *Eucalyptus* Honey Umarzai, Shannon–Weaver diversity index, F = Evenness

Table 4. Quantitative Melissopalynological analyses of different investigated honeys collected from different seasonal, botanical, and geographical origins.

Honey sample	APC/10 g honey	Maurizio's classes	Botanical source (Pollen species)
AHL-13	235×10^3	III	*Acacia spp.* (24%), *Ziziphus spp.* (20%) *Helianthus annuus* (20%),
EHJ-5	18×10^3	I	*Silybum marianum (10%) Acacia spp.* (35%) *Ziziphus spp.* (13%) *Silybum marianum* (13%)
ZHN-2	11×10^3	I	*Eucalyptus spp* (7%) *Callistemon citrinus* (6%) *Acacia spp.* (41%) *Foeniculum vulgare* (11%) *Ziziphus spp.* (21%)
AHN-7	18×10^3	I	*Acacia spp.* (60%) *Coriandrum sativum* (5%) *Ziziphus spp.* (5%)
AHS-10	15×10^3	I	*Helianthus annuus* (4%) *Eruca sativa* (4%) *Acacia spp.* (51%) *Eucalyptus spp.* (8%) *Ziziphus spp.* (10%)
AHG-19	255×10^3	III	*Eucalyptus spp.* (8%) *Helianthus annuus* (7%) *Acacia spp.* (55%) *Ziziphus spp.* (13%), *Silybum marianum* (5%)
AHT-21	11×10^3	I	*Coriandrum sativum* (5%) *Ziziphus spp.* (17%) *Acacia spp.* (33%) *Silybum marianum* (10%)
AHGu-12	12×10^3	I	*Eucalyptus spp.* (6%) *Ligustrum lucidium* (3%) *Acacia spp.* (62%) *Trifolium spp.* (6%) *Zea mays* (5%) *Ziziphus spp.*
EHK-6	22×10^3	II	*Eucalyptus spp.* (50%) *Acacia spp.* (7%) *Callistemon citrinus* (6%)
ZHT-13	16×10^3	I	*Ziziphus spp.* (6%) *Eucalyptus spp.* (52%) *Acacia spp.* (12%) *Ziziphus spp.* (8%)
EHG-9	8×10^3	I	*Eucalyptus spp.* (50%) *Acacia spp.* (17%) *Trifolium spp.* (7%)
EHU-14	15×10^3	I	*Ziziphus spp.* (6%) *Brassica campestris. (6%) Ziziphus spp.* (20%) *Eucalyptus spp.* (20%) *Acacia spp.* (19%) *Brassica campestris* (12%) *Eruca sativa* (7%)
EHS-16	12×10^3	I	*Ziziphus spp.* (29%) *Eucalyptus spp.* (13%) *Acacia spp.* (11%)

AHH-19	7×10^3	I	*Ziziphus spp.* (22%) *Foeniculum vulgare* (14%) *Acacia spp.* (13%) *Silybum marianum* (7%) *Malus domestica* (7%)
ZHM-24	23×10^3	II	*Callistemon citrinus* (11%) *Ziziphus spp.* (50%) *Eruca sativa* (12%) *Eucalyptus spp.* (8%)
ZHK-8	11×10^3	I	*Ziziphus spp.* (32%) *Acacia spp.* (24%) *Eruca sativa* (10%) *Brassica*
ZHSw-22	22×10^3	II	*campestris* (6%) *Ziziphus spp.* (40%) *Acacia spp.* (18%) *Helianthus annuus* (10%)
ZHS-11	265×10^3	III	*Silybum marianum* (6%) *Ziziphus spp* (49%) *Eucalyptus spp.* (15%) *Callistemon citrinus* (9%)
ZHG-1	15×10^3	I	*Ziziphus spp.* (23%) *Acacia spp.* (21%) *Helianthus annuus* (16%)
ZHU-4	19×10^3	I	*Callistemon citrinus* (7%) *Eruca sativa* (6%) *Ziziphus spp.* (51%) *Eucalyptus spp.* (8%) *Foeniculum vulgare* (8%)
ZHP-15	22×10^3	II	*Ziziphus spp.* (62%) *Acacia spp.* (12%) *Silybum marianum* (6%)
ZHZ-17	21×10^3	II	*Ziziphus spp.* (54%) *Acacia spp.* (21%) *Eucalyptus spp.* (6%)
AHZ-20	238×10^3	III	*Nicotiana tabacum* (6%) *Acacia spp.* (51%) *Ziziphus spp.* (22%) *Eucalyptus spp.* (6%)
AHM-18	21×10^3	II	*Acacia spp.* (54%) *Ziziphus spp.* (8%) *Silybum marianum* (6%)

Keywords: EHS = *Eucalyptus* Honey Serdhari, AHH = *Acacia* Honey Hathian, ZHM = *Ziziphus* Honey Mardan, ZHK = *Ziziphus* Honey Karnal Sher Kili, ZHSw = *Ziziphus* Honey Swabi, ZHS = *Ziziphus* Honey Shahmansoor, ZHG = *Ziziphus* Honey Gulabad, ZHU = *Ziziphus* Honey Umarzai, ZHP = *Ziziphus* Honey Pabbi, ZHZ = *Ziziphus* Honey Ziarat Kaka Shahib, AHZ = *Acacia* Honey Ziarat Kaka Shahib, AHM = *Acacia* Honey Muqam, AHL = *Acacia* Honey Lundkhawar, EHJ = *Eucalyptus* Honey Jalala, ZHN= *Ziziphus* Honey Nowshera, AHN = *Acacia* Honey Nowshera,, AHS = *Acacia* Honey Shahmansoor, AHG = *Acacia* Honey Gadoon, AHT = *Acacia* Honey Topi, AHGu = *Acacia* Honey Gulmaira, EHK = *Eucalyptus* Honey Katlang, ZHT = *Ziziphus* Honey Takkar, EHG = *Eucalyptus* Honey Gulabad, EHU = *Eucalyptus* Honey Umarzai, APC = Average Pollen Count

Table 5. Nutritional health benefits of Honeybee foraging flora.

Sr. No.	Taxa	F 5amily	Part Used	Honey/ Nectar Source	Phytochemical compounds	Health Benefits	Citations
1.	*Acacia modesta* Wall.	Fabaceae	Leaves, Fruit, Root	+++	Alkaloids, Cyclitols, Tannins	Cough, Bacterial Infection, Leprosy	(Sarwar, 2016)
2.	*Acacia nilotica* (L.) Delile	Fabaceae	Flower	+++	Phenolics, Epicatechol, Ellagic Acids	Gastrointestinal Problems, Tuberculosis, Anti-Mutagenic , Bronchitis	(AbdErahman et al., 2018)
3.	*Bidens pilosa* L.	Asteraceae	Whole plant, Seed, Root	+	Aliphatics, Flavonoids, Terpenoids	Digestive Complaints, Wounds	(Bartolome et al., 2013)
4.	*Brassica campestris* L.	Brassicaceae	Flower	+++	Flavonoids, Phenolics, Vitamins	Headache, Muscular Pain	(Haider et al., 2021)
5.	*Callistemon citrinus* (Curtis) Skeels	Myrtaceae	Root, Fruit, Leaves	++	Eucalyptol, Monoterpenes, Caryophyllene	Gastrointestinal Disorders, Infectious Diseases, Anti-Inflammatory	(Larayetan et al., 2017)
6.	*Centaurium pulchellum* (Sw.) Druce	Gentianaceae	Leaves	++	Secoiridoid Glycosides	Antti-Diabetic, Cardiovascular Disorders	(Siler and Misic, 2016)
7.	*Centaurea iberica* Trevir. ex Spreng.	Asteraceae	Whole plants, Stem	++	Steroid, Fatty Acids, Lactones, Flavones	Anti-Inflammatory, Wound Healing, Abdominal Pain	(Joujeh et al., 2019)
8.	*Cirsium arvense* (L.) Scop.	Asteraceae	Whole plant, Flower	++	Phenolics, Tannins	Liver Infection, Sore Throats	(Hossain et al., 2016)
9.	*Cleome viscosa* L.	Cleomaceae	Whole plant Root, Leaves	+	Polyphenols, Flavonoids, Flavone Glycoside	Ant-Diabetic, Arthritis, Malaria	(Soresh et al., 2020)
10.	*Dalbergia sissoo* DC.	Fabaceae	Whole plant, Seed	+++	Palmitoleic Acid, Triterpenoids, Capric Acid	Gonorrhea, Dermal Complaints, Nausea	(Ali et al., 2019)
11.	*Helianthus annuus* L.	Asteraceae	Whole plant, Flower	+++	Tocopherols, Flavonoids, Phenolic Acid	Heart Disorder, Pulmonary Infections, Whooping Cough	(Guo et al., 2017)
12.	*Lepidium didymum* L.	Brassicaceae	Whole Plant, Flower	+	Cardiac Glycosides, Tannins, Coumarins	Wound Healing, Relieving Fever,	(Akhtar et al., 2017)
13.	*Ligustrum lucidum* W.T.Aiton	Oleaceae	Leaves, Fruit, Seed	++	Phenylethanoids, Triterpenoids	Promoting Bones Health	(Che and Zong, 2015)
14.	*Malus domestica* Borkh.	Rosaceae	Fruit, Seed, Whole plant	++	Polyphenols, Phytosterols	Asthma, Inflammation, Anti-Diabetic	(Patocka et al., 2020)

15.	*Parthenium hysterophorus* L.	Asteraceae	Leaves, Roots	+	Alkaloids, Lactones, Sterols Proteins	Skin Infection, Dysentery Muscular Pain, Constipation, Insomnia	(Kaur et al., 2021)
16.	*Prosopis juliflora* (Sw.) DC.	Fabaceae	Flower, Seed	+++	Flavonol Glycoside, Alkaloids, Cinnamic acid	Asthma, Diarrhea, Skin Problems, Digestive Complaints	(de Brito Damasceno et al., 2017)
17.	*Silybum marianum* (L.) Gaertn.	Asteraceae	Whole plant, Flower	++	Flavonoids, Polyphenolics, Silybin,	Gallbladder Disorders, Kidney Infection	(Abinavoli et al., 2018)
18.	*Solanum surattense* Burm. f.	Solanaceae	Fruit, Leaves, Flower	++	Glycoalkaloid, Steroids, Steroidal Alkaloids	Anti-Diabetic, Leprosy, Throat Infection, Teeth Pain	(Tekuri et al., 2019)
19.	*Trifolium alexandrinum* L.	Fabaceae	Whole plant, Flower	+++	Iso-Flavonoids, Steroids	Skin Problems, Pneumonia, Stomach Ache	(Abdou et al., 2021)
20.	*Ziziphus oxyphylla* Edgew	Rhamnaceae	Fruit, Leaves, Stem	+++	Phenolic, Alkaloids	Jaundice, Gas Troubles	(Ahmad et al., 2017)

Keywords: +++ = Major Source; ++ = Medium source; + = Minor Source